GREEN INFRASTRUCTURE GUIDANCE MANUAL

DESIGNING LANDSCAPES THAT REDUCE STORMWATER VOLUME

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1.0 INTRODUCTION

1.1 Vision for Manual

This manual provides guidance for incorporating planned infiltration areas (PIAs) into site landscapes to reduce the volume of urban stormwater runoff and to protect downstream receiving waters. By implementing PIAs within development sites, the negative impacts of stormwater runoff are reduced by routing stormwater from impervious surfaces through dense vegetation (e.g., grass buffers, grass swales, and similar features) to slow runoff down, spread it out, filter it, and soak it in. Figure 1 shows an example of a PIA intercepting runoff from a roof drain.

Figure 1. Downspout leading runoff to grass for rainwater filtering and infiltration, photo credit: Wenk Associates

Implementing PIAs is a green infrastructure practice that reduces stormwater volume and comprises Step 1 of the City's Four Step Process to manage stormwater. Other practices such as bioretention, sand filters, permeable pavements, and constructed wetlands fall within Step 2 because they are designed to detain a water quality capture volume (WQCV) and slowly release it. Permanent control measures (PCMs) oriented toward Step 2 will not be discussed within this Manual but are covered in the *City of Colorado Springs Drainage Criteria Manual*.

This Green Infrastructure Guidance Manual is focused on implementing PIAs in site landscapes in order to support the application of stormwater volume reduction throughout the City. Although grass buffers and swales have been promoted in stormwater manuals for years, volume reduction by routing impervious areas to vegetated areas is a largely unrecognized opportunity that has been underutilized in practice. Criteria have advanced to give meaningful credit for volume reduction through infiltration, allowing Step 2 WQCV based measures to be reduced in size or eliminated. This Manual recognizes that the volume of stormwater infiltrating into the soil can benefit individual sites and, with widespread application, can make a positive difference in our watersheds.

Because each site is unique and the runoff reduction practices implemented must be site specific, this Manual does not present a prescriptive, "one-size-fits-all" approach. The guidance is written to describe the intent of PIAs, identify key principles, and provide context and examples for planning sites for stormwater volume reduction. The role of planners and designers is to apply these principles to create site plans and designs that lead to landscapes that are attractive and functional for stormwater management.

1.2 Organization of Manual

The Manual is organized in eight chapters, as follows:

- Chapter 1: Introduction – Presents the focus of the Manual, addressing Step 1 of the Four Step Process by routing stormwater runoff through vegetated PIAs that reduce volume.
- Chapter 2: Planned Infiltration Areas – Explains the background and practices related to PIAs and describes the hydrologic, water quality, and other benefits that these landscapes provide.
- Chapter 3: Site Planning for Stormwater Volume Reduction – Introduces principles of laying out individual sites and large-scale developments for stormwater volume reduction via PIAs.
- Chapter 4: Design of Topsoil, Vegetation, and Inflow Features – Informs designers about the basic components of PIAs that promote slowing, filtering, and infiltration of runoff.
- Chapter 5: Design Applications – Provides guidance for designing PIAs, illustrates a variety of typical applications, and summarizes factors influencing volume reduction estimates.
- Chapter 6: Site Examples – Demonstrates how volume reduction might be implemented on a variety of commercial and residential sites.
- Chapter 7: Definitions – Explains many of the technical terms used in the Manual.
- Chapter 8: References – Lists sources of information that were referred to in the Manual.

2.0 PLANNED INFILTRATION AREAS

2.1 Description

PIAs are vegetated, pervious areas that intercept runoff from nearby impervious surfaces (e.g., parking lots, roofs, roadways) to provide hydrologic and water quality benefits. Flow through PIAs for the water quality event and other small rain events is designed to occur as shallow sheet flow that interacts with dense vegetation to slow down the runoff and promote filtering and infiltration. Examples of PIAs include grass buffers and grass swales without underdrains, although PIAs may comprise a variety of landscape forms that create similar conditions. Figure 2 depicts a PIA receiving runoff from an adjacent street in a residential community.

Figure 2. A curbless concrete edge allows runoff from a neighborhood street to enter this PIA via distributed sheet flow

Figure 3 depicts a typical cross section through a grass buffer in comparison to conventional raised landscaping next to a parking lot or roadway. It illustrates the similarities and differences between the two practices. The characteristics desired for PIAs are the same as for any landscaping – good soil and thriving vegetation. The main difference for PIAs is to grade the surface of the landscape to be slightly below adjacent pavement to allow runoff to flow into the landscape, as opposed to elevating the landscape and surrounding it with a curb. PIAs can be integrated into any vegetated area – open spaces, parks, stream corridors, or site landscaping.

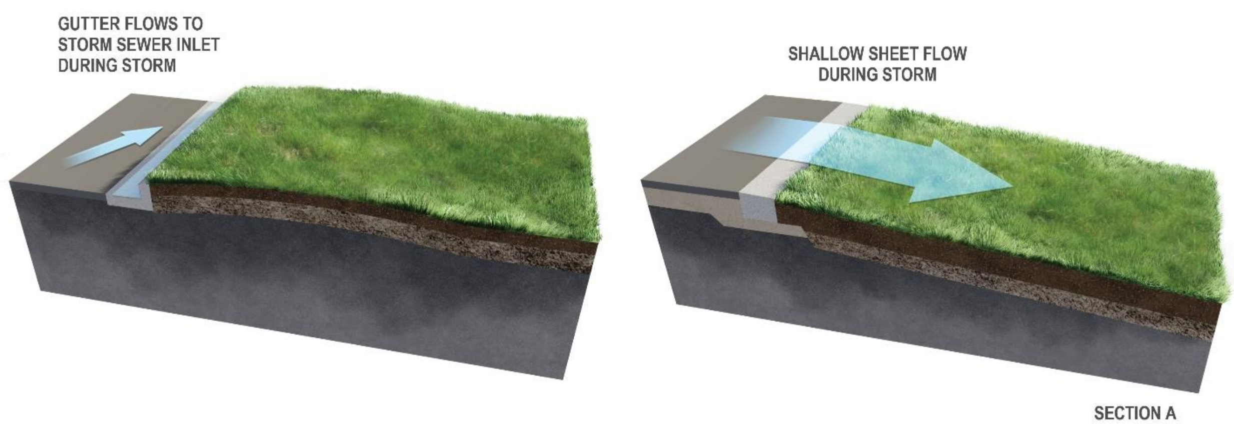


Figure 3. Comparison of conventional raised landscaping (left) to grass buffer (right)

PIAs are a relatively simple practice compared to bioretention, which requires additional depth and may require an outlet structure, an underdrain in low-permeability soils, and retaining walls in tight spaces. Unlike bioretention systems that are designed to detain water during storm events, PIAs are shallow and free draining so they do not hold water. During frequent storms such as a water quality event, runoff takes the form of shallow sheet flow that experiences high resistance as it flows through the vegetation, slowing the runoff down. With favorable topsoil and healthy vegetation, PIAs can achieve high infiltration rates in these smaller storm events where sheet flow is achieved. Because of their relative simplicity and lack of structure and underdrains, PIAs as described in this Manual do not require special easements.

PIAs are termed receiving pervious areas (RPA) in the *Drainage Criteria Manual* in the context of describing hydrologic modeling to estimate runoff and infiltration for various land covers within a site or subcatchment. The *Drainage Criteria Manual* also describes this practice as "minimizing directly connected impervious areas" (MDCIA) since in it roofs and pavement are disconnected from direct conveyance into gutters and storm sewers. In the City, the term green infrastructure refers to Step 1 stormwater infrastructure intended to mimic natural infiltration processes and includes the implementation of PIAs in to achieve stormwater volume reduction.

2.2 Benefits of Planned Infiltration Areas

2.2.1 Managing Stormwater

PIAs use vegetation to reduce stormwater peak flows and volumes and improve water quality by filtering stormwater runoff. In an undeveloped watershed, most precipitation on an annual basis is intercepted by vegetation, detained in small depressions in the land surface, and infiltrated into the soil (infiltration is the largest loss), such that there is little surface runoff. The key to the high infiltration rates found in healthy, natural watersheds is an active soil ecosystem – a synergy of organic, biologically-active topsoil, densely-rooted vegetation, and water. Well-designed PIAs mimic these natural processes and establish a stable land cover that slows down flow, sustains infiltration processes, and reduces surface runoff and erosion.

Figure 4 shows impervious surfaces (e.g., roadways, parking lots, sidewalks, roofs) typical of any urban or suburban area. In this case, there is a small amount of detention in depressions on roofs and pavement and some infiltration in pervious areas, but most of the rainfall runs off. Although urban areas include landscaping, traditional drainage systems bypass landscaped areas and carry runoff directly from impervious surfaces to concrete conveyances (e.g., curb and gutters, storm sewers) straight to downstream receiving waters. Runoff is conveyed quickly through the traditional storm sewer system and washes pollutants (sediment, metals, nutrients, pathogens, oil, atmospheric fallout, salts, organic matter, litter, etc.) to our streams.

Figure 4. Impervious surfaces are inherent to urban landscapes, generating increased peaks, volumes, and frequency of runoff

Increased stormwater runoff peak flows and volumes due to urbanization lead to broader impacts such as elevated risk of flooding, channel degradation, and water quality impairments to receiving waters. Channel degradation, including headcutting and bank failures, can put nearby structures at risk. Degraded channels like the one shown in Figure 5 are being addressed through the City's stream restoration program, but this requires significant capital expenditures. Additionally, degradation from increased urban runoff can lead to vegetation and habitat deterioration along channels due to floodplain and groundwater disconnection. As demonstrated in Figure 6, excessive nutrients (a stormwater pollutant) in runoff can cause algal blooms and fish kills in receiving waters. These adverse impacts of stormwater runoff can have major economic and societal ramifications.

Figure 5. Channel degradation from excessive urban runoff impacts streams and requires significant capital expenditures to restore

One of the primary benefits of designing site landscaping to MDCIA is to reduce urban stormwater impacts and protect stream systems. The concept of directing runoff from impervious areas to vegetated PIAs such as buffers and swales (instead of routing it directly into storm sewer systems) is inherently resilient, as it replicates natural hydrologic processes and can be used to reduce the required storm sewer infrastructure at a site. Resiliency is further enhanced when these areas are vegetated with low-water requirement, native grasses and plant species that can survive with minimal (if any) supplemental irrigation once established.

Figure 6. Excess nutrients in stormwater runoff can lead to water quality impairments including algal blooms, photo credit: Colorado Springs Gazette

2.2.2 Enhancing Sites and Communities

In addition to their hydrologic and water quality benefits, PIAs provide the many benefits of site landscaping as identified in the City's Landscape Code and Policy Manual (Landscape Code, 1998). PIAs, like all thoughtfully created landscapes, introduce the beauty of nature into communities, creating habitat for local wildlife and providing flowers that attract pollinators. Trees within PIAs provide shade, can help to reduce the effects of urban heat islands, and intercept rainfall preventing it from becoming runoff. The residential community shown in Figure 7 was planned with the vision of conveying runoff in vegetated swales rather than in storm sewers to create an attractive open space network that adds value to the neighborhood.

PIAs offer financial benefits. They have the potential to reduce construction and long-term maintenance costs by reducing grey infrastructure (e.g., storm sewers and structural channel elements). By treating stormwater as a resource rather than a waste product and by encouraging the use of native vegetation, PIAs support water conservation by reducing potable irrigation needs.

Figure 7. A thoughtfully designed network of vegetated swales adds value to this residential community

2.2.3 Planned Infiltration Areas in Semi-Arid Climates

Colorado Springs faces the challenges of establishing vegetation in a semi-arid climate. PIAs depend on healthy and resilient vegetation to properly function. Achieving areas of healthy vegetation in the climate of Colorado Springs requires landscape plans that consider the site-specific soil and hydrologic conditions. The approaches promoted in this manual rely extensively on the guidance provided in the Landscape Code to ensure that PIAs are suited to local conditions.

This Code encourages establishing dense grass cover using native species and limiting the application of irrigated turf. Utilizing plant communities that are native to Colorado Springs' soils and climate allows for lower installation, establishment, and maintenance costs. Native sod-forming grasses create high roughness that helps to slow flow, provide deep root systems to aid infiltration, are attractive, have low fertilization and mowing requirements, and most importantly in a water-scarce, semi-arid climate, require less water. Certain native grass species are well suited to the varied hydrology of PIAs – from dry between rain events to having additional water applied from upstream roofs and pavement during storms. Irrigated turfgrass sod provides similar hydrologic benefits within PIAs (sand-grown sod is recommended); however, irrigated turfgrass is prohibited in some locations and if implemented, should be in limited amounts.

The City, through Parks, Recreation and Cultural Services (PRCS) in coordination with Colorado Springs Utilities, has implemented a program to convert portions of City parks from Kentucky bluegrass to native grasses (Becker, 2016). This program has demonstrated that the use of native grasses has reduced mowing frequency, fertilizer requirements, and aeration and irrigation costs as compared to non-native grass species. Even with these advantages, the native grasses reflect a neat, maintained appearance, as shown in Figure 8. The knowledge gained from the PRCS native turf conversion program, including successful native grass seed mixes and seeding application rates, was used to inform this guidance.

As part of the Manual development, site soil, vegetation, and infiltration conditions were evaluated at several locations around the City, in which both irrigated turfgrass and native grass areas were tested. Agronomic lab analyses indicated soil characteristics at each site favorable for plant growth and infiltration; salts were low, pH and nutrients were suitable, organic matter was high, and textures were generally sandy loam. Infiltration testing confirmed the influence of vegetation on infiltration; the highest infiltration rates were observed in the sites with the densest grass cover. The soil and infiltration testing provided a snapshot of local conditions and demonstrated soil, vegetation, and infiltration characteristics suitable for PIAs.

Figure 8. The City's native turf conversion program has demonstrated that native species have reduced mowing, fertilizing, and irrigating requirements while maintaining a dense, neat appearance

3.0 SITE PLANNING FOR PLANNED INFILTRATION AREAS

3.1 Principles for Laying Out the Site

1. **Consider volume reduction early**. Laying out a site with PIAs is best considered at the beginning of the development process. Sizing and positioning landscape areas to intercept runoff needs to be included within the initial effort of siting lots, buildings, roads, and parking.
2. **Let the topography and natural features of the site inform layout.** Based on a site assessment (described in Section 3.4), designers should seek to preserve portions of the site that add value to the development, such as stream corridors, wetlands, mature trees and native vegetation, and areas with high infiltration rates. This is especially beneficial if preserved areas can fulfill parks, open space, landscape, and stormwater management goals more effectively and at lower cost than recreating and revegetating a disturbed, graded site. With this approach, the site layout is focused on siting buildings, roadways, and parking in the areas outside the preserved areas.
3. **Reduce site imperviousness**. Reducing impervious surfaces through creative site layout will generate less stormwater runoff, reduce the size and extent of PCMs required, and save on initial capital cost and maintenance, repair, and replacement over time. Approaches that may be considered include shrinking building footprints by building up rather than out, reducing paved plaza areas, using permeable pavements, reducing parking spaces, narrowing drive lanes, using looped street configurations in residential developments, reducing knuckles and local street radii, and creating shared access lanes and parking. These techniques need to be coordinated with City departments to ensure City Code requirements are being met.
4. **Achieve multiple objectives**. Identify where landscape areas can perform multiple functions called for in the City's Landscape Code. Utilize landscaping to fulfill volume reduction objectives in addition to site landscape requirements such as parking lot landscaping, perimeter buffering and screening, or interior landscape area requirements.
5. **Reduce storm sewer length**. Seek ways to convey runoff in grass swales (a form of PIA), where possible, to reduce the length of storm sewer required. This not only saves initial capital and long-term maintenance costs associated with storm sewer networks, but also allows for swales to filter and infiltrate runoff, benefiting downstream receiving waters.
6. **Capture roof and pavement runoff**. The greater the amount of impervious area runoff directed to PIAs, the greater the stormwater volume reduction. The design goal is to route as much of a site's roof and pavement area to PIAs as feasible, while keeping appropriate loading rates in mind.
7. **Quantify volume reduction concurrent with site layout.** Use methods referred to in Section 5.3 to check runoff reduction in PIA features as the site is being laid out. This will provide an idea of the necessary sizes of PIAs relative to the upstream impervious areas, while there is still opportunity to adjust the site layout to achieve overall runoff reduction goals.

3.2 Planning Individual Sites

Site planning for stormwater volume reduction on individual sites (e.g., retail, office, industrial, multi-family) is primarily focused on laying out building footprints, parking, and access lanes in concert with landscape areas. This includes both PIAs to capture and infiltrate runoff and conventional landscaping in areas not conducive for runoff capture. The City's Landscape Code provides extensive guidance to landscape planning on a site. Often, landscape areas can serve multiple purposes; a grass buffer and swale can fulfill volume reduction requirements, while also serving as a perimeter screening buffer.

Perimeter landscaping is often sloped to make up grades with adjacent topography. If downward sloping perimeter areas are used as PIA practices, they either need to fully achieve the stormwater management requirements that allow runoff to flow offsite, or they need to lead to a swale or storm sewer that collects runoff before it leaves the site to convey it to one or more PCMs. Runoff may flow into and then out of a PIA in the interior of a site, as long as it gets conveyed to any required PCMs before it leaves the site.

3.3 Planning Large Scale Developments

Site planning for stormwater volume reduction is best applied holistically on the largest scale possible. Large master planned developments that cover dozens or hundreds of acres offer expanded opportunities to plan for volume reduction and other stormwater measures on a regional or sub-regional basis. In addition to planning backbone roadway and utility infrastructure for multiple filings and lots, a network of stream corridors can serve as the foundation for a comprehensive stormwater management system integrating swales, streams, and floodplains and PCMs for water quality and flood control. The goal of such a system is to stabilize the stream network and maximize the safe surface conveyance of stormwater, rather than rely on underground conveyance, to lengthen vegetated flow paths and slow runoff for increased filtering and infiltration.

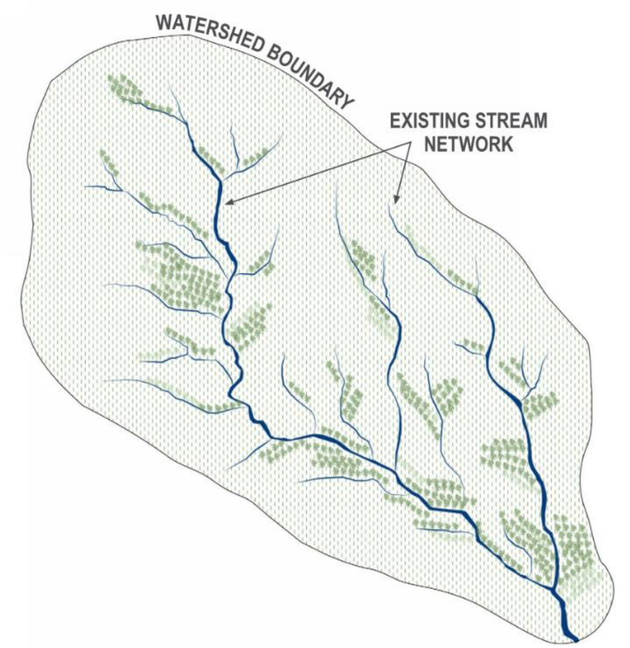


Figure 9. Preserving much of the existing branched stream network and laying out development in adjacent spaces provides the foundation for a functional surface conveyance and open space system

An existing stream network and watershed is shown schematically in Figure 9. For projects that cover all or a substantial portion of a watershed, a critical planning step is to lay out development areas in a manner that preserves open space corridors along existing streams or created swale alignments, ideally extending upstream to reach subcatchment areas in the 10-to-50-acre range. If the stream network can serve as a thematic element of a development's parks and open spaces, it can create a foundation for the community's overall stormwater management approach. This approach to development has been called a "dendritic approach" because the streams resemble the same pattern as branches of a tree.

A finer, branched open channel network can replicate the function of natural first and second order streams. Using well-vegetated swales and small drainages within this network implements a form of PIAs that works to slow flow velocities, infiltrate and filter runoff, and attenuate peak flows. Weaving a vegetated open channel network throughout a development is an effective technique for reducing the length and sizes of storm sewer required, reducing initial capital, and long-term replacement costs.

3.4 Initial Site Assessment

The first step in successfully implementing stormwater volume reduction is understanding existing site conditions. The site assessment will look different for developments at varying scales; large undeveloped sites may possess a network of existing streams, riparian corridors, and other natural features that will require a comprehensive assessment. Smaller sites and infill projects that have fewer existing natural features still benefit from a thorough, though reduced assessment. The site assessment involves gathering desktop and field data described in the categories below, looked at through the lens of implementing PIAs.

3.4.1 Site Visit

A critical aspect of the overall site assessment is the site visit. A walk of the site that includes representatives of the owner, developer, and design team can help the project team gain an understanding and appreciation of the existing natural resources and site constraints and an awareness of opportunities to manage stormwater closer to the source.

3.4.2 Topography, Hydrology and Drainage Patterns

An understanding of the topography, hydrology, and water features on a site will assist in the identification of high-quality natural resources that may be able to be preserved or enhanced during development.

Use topographic mapping and aerial imagery to identify existing drainage patterns and water features on site including:

1. Streams, floodplains, and ephemeral drainages
2. Wetlands, seeps, and springs
3. Ponds and closed depression areas
4. Ridges, drainage divides, and slope aspects
5. Existing desirable landforms (rock outcroppings, etc.)
6. Existing infrastructure

3.4.3 Existing Site Soils

A topsoil investigation provides value from an agronomic standpoint and a subsoils investigation provides value from a geotechnical standpoint. The goal of the topsoil investigation is to understand the variety of topsoil characteristics throughout the site and to identify the best soils for preservation, if development can be sited outside these areas, or for use in PIAs or other landscape areas. Both small- and large-scale sites can benefit from a thorough topsoil investigation as even the smallest project site may contain multiple soil types that could be best used in different applications.

Site geotechnical reports are typically not well suited to comment on topsoil health. However, there are desktop resources from the US Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Web Soil Survey and local criteria documents to assist the project team assessing topsoil quality on a site, including the City's *Stormwater Construction Manual* (2020).

3.4.4 Existing Onsite Vegetation

Figure 10. An assessment of vegetation communities on site provides insight into areas that may be able to be preserved and enhanced as part of a stormwater conveyance and treatment system

An important element of the site assessment is to inventory the type, density, and health of existing vegetative communities as they relate to the drainage network and site soils. Identify areas of vegetation consisting of desirable native species, such as indicated in Figure 10, that are relatively weed free which can be preserved along streams and riparian areas or for volume reduction. The vegetation on site may also give clues to the topsoil quality; if the vegetation is sparse or characterized by noxious or listed weed species, the soil may not be ideal. Conversely, a healthy stand of native species may be indicative of favorable topsoil conditions. Thriving, desirable native species present onsite can help inform the seed mixes ultimately selected for a site, including species to be used for PIAs or other landscaping.

4.0 DESIGN OF TOPSOIL, VEGETATION, AND INFLOW FEATURES

The primary components of PIAs are topsoil, and vegetation, and inflow features. Specific design guidance for each of these three components is provided in this chapter.

4.1 Topsoil

Figure 11. Healthy topsoil conforming to specified parameters is critical to the function of PIAs

Designing functional PIAs (e.g., grass buffers, swales and similar features) starts with specifying suitable planting media consisting of organic, loamy, and biologically active topsoil. The layer of topsoil below the vegetative cover, shown in Figure 11, is critical to the success of the grasses and plants and the infiltration capacity of a PIA. Healthy topsoil provides a suitable textural, structural, and chemical/agronomical environment to host biological organisms, support vegetation, and sustain high infiltration capacity. Soil helps seeds germinate by providing a media to hold the seed at the proper depth and receive the appropriate amount of water, air, and warmth. Once seeds sprout, topsoil and soil organisms continue to provide plants with what they need to grow and thrive. These natural soil and vegetation processes lead to sustained infiltration capacity over time.

The following paragraphs describe desirable topsoil characteristics for PIAs.

4.1.1 Texture

Texture pertains to the proportions of sand, silt, and clay particles in soil. Since sand, silt, and clay particles vary widely in size, shape, and reaction with water, varying proportions of these particles create dramatically different physical properties in soil.

Figure 12 shows the US Department of Agriculture (USDA) texture triangle and various texture classifications associated with specific proportions of sand, silt, and clay. The three "points" of the triangle reflect pure sand, silt, and clay without the influence of the other particles. Determining the texture of a sample of soil is based on a laboratory gradation analysis using sieves and hydrometer methods to estimate the percent sand, silt, and clay according to USDA definitions of particle sizes.

Figure 12. USDA soil triangle showing various textures based on percentage of sand, silt, and clay

Sand and clay often present opposite characteristics. For instance, sand is more permeable, but can't hold water or nutrients; clay has a high water and nutrient holding capacity but has lower permeability. Neither alone are good for a planting media aimed at sustaining both plant health and infiltration capacity.

Fortunately, there is a range of loam textures that balance the extremes of sand and clay and exhibit the most desirable properties for topsoil. Of the loam soil textures, the sandy loam texture represents a "sweet spot" that has both relatively high infiltration rates and significant moisture and nutrient retention for plant health; therefore, sandy loam is the recommended texture to specify for topsoil in PIAs. Other textures, including loam, sandy clay loam, and clay loam may also be suitable for topsoil in PIAs, although at lower infiltration capacities.

4.1.2 Soil Organisms

The ideal topsoil for PIAs will contain – initially or built up over time – a rich, diverse community of organisms that provides a complex series of functions to support plant health and enhance infiltration processes. Specifications for topsoil stripping, stockpiling, and placement practices that preserve live roots and soil organisms are recommended. On large sites, a rotational approach for stripping and placement to reduce stockpiling and double handling may be considered. Topsoil stockpiles are recommended to be left as low and uncompacted as possible and a cover crop is recommended to maintain live roots in the soil. Limiting the time that topsoil is stored in stockpiles is ideal to keep organisms alive.

How do soil organisms benefit plant health and infiltration?

Large fauna, such as worms, insects, mites, and nematodes, burrow through the soil, creating tunnels and pores that provide for aeration and water infiltration. Fungi are a class of organisms that enhance plant health and infiltration; mycorrhizae fungi attach to plant roots and extend their network, exchanging water and nutrients. Fungi also assist with soil aggregation, which in turn enhances infiltration (Soil Society of America, 2012). The smallest and most numerous organisms found in soil, such as bacteria, archaea, and actinomycetes, are active in the decomposition and recycling of elements. A result of these processes is the building of organic matter in the soil. Organic matter is one of the most important elements in soil and is beneficial for plant health and infiltration (Brevik, 2010 and Lehman et al., 2015).

Limited use of certain compost amendments may be considered to boost biological health of the topsoil; however, care is required to assess compost sources, properties, and application rates to avoid introducing undesirable substances into the soil or generate nutrient export in surface or subsurface waters.

4.1.3 Chemical/Agronomic Properties

Chemical and agronomic properties of soil are important in addition to topsoil texture and biological communities. The City's *Stormwater Construction Manual* identifies chemical and agronomic properties to consider when assessing the suitability of topsoil for PIAs, along with recommended amendments. As mentioned above, careful consideration of compost amendments is recommended as a way to increase organic matter, a parameter beneficial for plant health and infiltration.

4.1.4 Avoidance of Compaction

Disturbance, and the associated compaction (as represented in Figure 13), destroys soil structure and inhibits infiltration. Desirable soil structure develops as a result of freeze-thaw cycles, burrowing and tunneling by larger soil fauna, and the effect of biological "glues" produced by the smaller soil organisms that bind particles together (Soil Society of America, 2012). Soil structure may contribute more to porosity and infiltration capacity than soil texture (Skorobogatov, 2020).

Figure 13. Compaction destroys soil structure and inhibits infiltration; care is needed to avoid or mitigate compaction effects, photo credit: iStock

It is ideal to lay out large-scale developments in a manner that avoids disturbance and the compaction of soils within open spaces and drainage networks. This will help to preserve healthy, well-structured soil in place. While this can be difficult, it is critical to avoid compacting soils that are beneath PIAs. If disturbing soils is necessary, steps should be taken to scarify the subgrade under the topsoil to allow for penetration by roots, air, and water.

4.2 Vegetation

The other essential component of PIAs, beyond healthy topsoil, is densely rooted vegetation. Section 4.2.2 provides design guidance for vegetation in PIAs, but first, it is important for designers to understand vegetation's critical influence on infiltration processes.

4.2.1 Vegetation's Influence on Infiltration

As mentioned in Section 2.2.3, field testing that applied measured volumes of water to produce sheet flow over a variety of soil and vegetative conditions was conducted in Colorado Springs during the preparation of this Manual. Figure 14 shows the setup used to observe in-situ sheet flow infiltration. The sheet flow testing demonstrated what has been shown in similar testing in the region since 2012 – that sheet flow infiltration associated with shallow depths of water moving through turfgrass are comparable to or slightly greater than rates observed using a double-ring infiltrometer. Further, research shows that sheet-flow infiltration is most strongly associated with the density of vegetation and that vegetation can be more influential than the type of soil. Although clayey soils are not recommended for PIA practices, higher sheet flow infiltration rates have been observed in tests on clay loam soils that had dense turf cover compared to sandy soils that had poor grass cover (Muller, 2015).

Figure 14. Water added at a rate replicating runoff during the water quality event provided a sense for sheet flow infiltration characteristics in a variety of local soil and vegetation conditions

Role of vegetation in promoting and sustaining infiltration processes

In addition to local, applied infiltration testing, research in the fields of agronomy and stormwater management has demonstrated the benefits of vegetation in promoting and sustaining infiltration processes. Factors that account for vegetation's positive effect on infiltration include:

1) Dense vegetative cover stabilizes the ground surface against erosion and reduces the likelihood of fine soil particles sealing the surface of the soil (NRCS, 2015).

2) The shoots and roots of dense turfgrass create macropores, or passageways, into the soil; this is especially true for native grasses that possess root structures that may penetrate several feet below the ground surface (Muerdter et al., 2018).

3) Dense turf provides high flow resistance, especially when flow depths are less than the height of grass shoots (Wilson, 1967), which helps to slow down flows, confine the wetted area, prolong infiltration processes, and attenuate peak discharges.

4) Vegetation evacuates water from pore spaces through evapotranspiration to increase holding capacity for the next storm event (Skorobogatov, 2020).

5) Decaying plant matter helps form a protective surface mulch and adds organic matter to the soil (Soil Society of America, 2012).

When shallow sheet flow conditions are achieved (runoff depth is less than the height of grass shoots), the high hydraulic roughness of the grass shoots promotes slow velocities (typically one foot per minute or less compared to one foot per second or greater in a concrete gutter pan). The increased travel times and impacts of the vegetation shoots and roots provide the conditions and extended time for effective filtration and infiltration.

4.2.2 Vegetation for Planned Infiltration Areas

The ideal vegetation for PIAs is comprised of sod-forming grasses, sedges, rushes, and forbs that provide both roughness to slow and spread runoff and thick shoots and roots to enhance and sustain infiltration. The densely rooted vegetation may be supplemented by trees and woody shrubs; however, the use of cobble and mulches in planting beds requires special considerations as discussed further in this section.

4.2.2.1 Seeded, Native Sod-forming Turfgrass

Consistent with the City's Landscape Code, native species of grasses and other vegetation are recommended for landscapes, whether used for volume reduction or not. Native species are suited to the local climate and soils, have deep root systems, and have lower water requirements than non-native grasses. Native grass species can be tailored to a variety of uses, appearances, and maintenance practices. Figure 15 illustrates a mowed turfgrass cover that has been established as part of the PRCS conversion program. The native grass cover has a maintained, lush appearance while reducing mowing frequency, fertilizer requirements, and supplemental irrigation. Figure 16 depicts a native grass installation with a natural appearance that is intended to be mowed infrequently.

Figure 15. PRCS has used sod-forming varieties of native grasses to establish dense turf that is regularly mowed for a neat appearance yet has reduced irrigation requirements

Native grass mixes should include a variety of species specifically suited to the conditions of PIAs being designed and should consider site specific aspects such as soil, hydrology, and shade. It is recommended that rhizomatous sod-forming native turfgrass species dominate the mix, although some bunch-type species are acceptable. Sod-forming grasses are recommended to reduce the likelihood of preferential flow paths which can lead to erosion. Species with a large hydrologic amplitude – from dry to wet – are recommended. The species mix and application rates should be selected by a qualified specialist (often an ecologist or landscape architect)

Figure 16. Native seed mixes are an alternative to bluegrass sod, photo of native grass and wildflower mix taken two months after seeding in Colorado

based on the desired characteristics of the established vegetation. Important aspects to consider are the proportion of cool and warm season grasses, the mature height of the grasses, and the addition of supplementary species (e.g., wildflowers, sedges, rushes). To help establish a dense stand of grass quickly, application rates as high as three to four pounds per 1,000 square feet have been used by PRCS staff during the native grass conversion program. If non-native species are proposed for establishment by seeding, this should be in conformance with requirements within the City's Landscape Code.

Seeding should take place immediately after the planting media is installed, and a biodegradable 100-percent coconut erosion control blanket (shown in Figure 17). This recommended phasing will help to reduce the likelihood that fine silts and clays are mobilized by applied water to form a low-permeability layer on the planting surface.

Figure 17. A biodegradable 100% coconut blanket is recommended immediately after native seeding

4.2.2.2 Sand-grown Sod

If non-native turfgrass sod is used on a site (application is limited under the City's Landscape Code), sand grown turfgrass sod is recommended to reduce the likelihood of creating a low permeability layer at the top of the planting media. Sand grown sod is typical of the grasses installed in many sports stadiums, is grown in Colorado, and is available locally.

4.2.2.3 Trees and Shrubs

Trees and woody shrubs may be considered in addition to grasses, especially for multi-functional landscapes (achieving Landscape Code requirements, visual screening, shade, etc.). Trees should be selected to be compatible with a dense understory of grasses to avoid developing bare soil conditions under the woody overstory, with careful consideration of the impacts of shade trees and evergreens on the PIAs. Tree planting installation details need to indicate how to allow the shallow distributed flow pattern to continue around the slightly elevated tops of root balls. If shrub beds are placed in locations that receive inflows from impervious areas, cobble ground cover is recommended in the shrub bed to reduce the likelihood of erosion; however, shrub beds and evergreens should avoid being placed in buffers or at the bottom of swales to allow unconstrained sheet flow within dense vegetation.

4.2.3 Mulch and Ground Covers

Figure 18. Cobble has reduced infiltration capacity compared to dense turfgrass and is difficult to maintain if clogged with sediment

The use of mulch and ground covers in PIAs requires special considerations. Wood mulches and smaller gravels are not recommended within runoff flow paths as they are subject to washing away. If a ground cover is used in addition to dense vegetation, cobble or coarse landscaping rock is preferred. If a wood mulch is used, shredded, fibrous material that binds with itself to form a mat (sometimes called "gorilla mulch") is preferred outside flow paths. Cobble and mulch are less suitable than turf-forming grasses because they will not have the same sustained infiltration characteristics as dense grasses due to the reduced influence of shoots and roots and the presence of weed barrier fabric. As shown in Figure 18, cobble is subject to clogging from surface sediment deposits and, once clogged, is difficult to maintain. Reduced infiltration rates for cobble and wood mulch are discussed in the *Drainage Criteria Manual*.

Placing cobble along the edge of the pavement in shrub beds will provide erosion protection in a location where it would be difficult to establish dense grasses. In this case, it is important that the top of cobble is set several inches below the pavement edge to avoid blocking inflows. Care is required to detail the relative elevations of plants, cobble, and infiltrative surfaces of PIA practices, as well as indicating the presence of weed fabric under cobble and any dividing features at interfaces of cobble and grass.

Because cobble and mulch will have lower sustained infiltration rates and can be difficult to maintain as they become filled with sediment, debris, and/or weeds, it is beneficial to maximize the extent of densely rooted, native vegetation and to minimize the proportion of cobble and mulch within PIAs.

4.2.4 Irrigation

A suitable permanent irrigation system is highly recommended for vegetated landscapes, including PIAs. However, with the addition of runoff from upstream impervious surfaces during rainfall events, it is anticipated that watering requirements may be reduced after initial establishment, especially for native grass covers. Depending on the ratio of the wetted area of the vegetation to the upstream impervious area, the vegetation could receive multiples of the annual precipitation depth during a growing season.

4.3 Inflow Features

4.3.1 Roof Drains

Figure 19. A series of roof drains discharge into a grassy area for filtering and infiltration

One important design consideration is how to direct runoff from the roof drains and pavement edges into PIAs. Figure 19 shows a series of roof drains discharging to an infiltration area set out from a building. PIAs receiving runoff from roof drains should be located sufficiently away from buildings to reduce the likelihood of negative effects on buildings, and roof drains should be designed to avoid discharging water into the foundation's backfill zone. Slopes adjacent to buildings and the appropriate design of roof drains and infiltration zones in relation to buildings and foundations should be based on the recommendations of a geotechnical engineer. Because runoff from roof drains is concentrated flow, it may be beneficial to design a flow spreading feature, such as a level-spreader, to distribute runoff in an infiltration area to achieve sheet flow.

4.3.2 Pavement Edges and Curbs

A concrete transition feature, such as the one shown in Figure 20, is recommended at the interface between pavement and PIAs. The concrete edge treatment should be designed to provide separation between the landscape and the pavement and reduce the likelihood that infiltrated water could negatively affect the pavement. The depth of the concrete edge, subgrade preparation under the concrete edge and pavement, and pavement design (determination of type of pavement and base course, with design thicknesses and specifications) should be based on recommendations from a geotechnical engineer.

Figure 20. Concrete edge treatment is recommended at the transition from pavement to a PIA

The concrete edge may be curbless, curbless with flow-through parking blocks (in parking lots) or include one of several flow-through curb configurations. Curb openings may be designed similar to a curb-opening inlet, without the inlet box, to create a smooth curb face for snow plowing operations. Figure 21 shows a cast iron option for a curb opening; a steel frame is shown in Figure 22. Another design option is to allow flow to be conveyed through slotted curbs that have 1.5-inch or 2-inch gaps every one to two feet or small rectangular openings at

Figure 21. A variety of flow-through curbs can be considered, this figure shows a cast iron frame for a small curb opening

the flowline tapered to larger openings at the back of curb to reduce plugging potential. Having more continuous open area along the pavement edge will allow for more distributed sheet flow within the PIAs. For curbless pavement edges, it may be beneficial to use fence, bollards, or cobble just beyond the edger to reduce the likelihood that vehicles will leave the pavement and cause wheel ruts in the landscape. As mentioned, concrete edgers and flow-through curb concepts need to consider maintenance operations such as snow plowing and debris removal.

Figure 22. A steel frame for this flow-through curb creates a smooth face for snow plowing operations

A drop off from the pavement to the top of the planting media (or top of cobble, if used) is recommended to reduce the likelihood that sediment and biomass will build up and block the flow of water off the pavement. The recommended drop off height is three inches to the top of the soil surface for seeded grasses, the top of sod for sodded grasses, and the top of cobble for rock ground cover.

5.0 DESIGN APPLICATIONS

Applying PIAs on a site should be a coordinated effort within the development project team; in addition to owner representatives, this may include planners, architects, civil engineers, geotechnical engineers, structural engineers, landscape architects, ecologists, irrigation specialists, and others. It is incumbent on the design team to consider pertinent issues associated with volume reduction via onsite infiltration and address them. If conditions exist that may restrict the implementation of PIAs (e.g., contaminated soils, highly expansive soils, high water table or bedrock), these need to be taken into account and mitigated or avoided.

5.1 Typical Applications

This chapter illustrates some of the ways PIAs may be situated to receive runoff from upstream roofs or pavement. As each site is unique, many other applications and designs may be considered. In each application shown, narrow blue arrows indicate how stormwater runoff enters the PIA practice and wide blue arrows illustrate the flow direction of the shallow sheet flow within the PIA that will occur during frequent, small storm events. Further detail on the cross sections of the PIA applications is provided in Section 5.2.

The management of surface and subsurface water is a critical design consideration for PIAs. Besides creating shallow sheet flow conditions in small storms, the conveyance of runoff during larger storms needs to be addressed during the design. As mentioned, proximity to buildings, adjacent pavement sections, compacted subgrade, and edge treatment design should be based on the recommendations of a geotechnical engineer cognizant of the effects of infiltration of runoff in PIAs during storms and irrigation application.

5.1.1 Roof Drains

Figure 23 and Figure 24 depict PIAs intended to convey and spread runoff from building roof drains. Application 1 illustrates the use of a level spreader to distribute the concentrated flow from a roof drain over a wider area, promoting greater slowing, filtering, and infiltration of roof runoff. Application 2 takes roof runoff from a drain directly into a grass swale. This swale is shown running parallel to the building, allowing multiple roof drains from a building to be conveyed into the swale. As stated in Section 4.3.1, the proximity of PIAs adjacent to buildings and the extension of drains beyond the foundation backfill zone should be based on the recommendations of a geotechnical engineer.

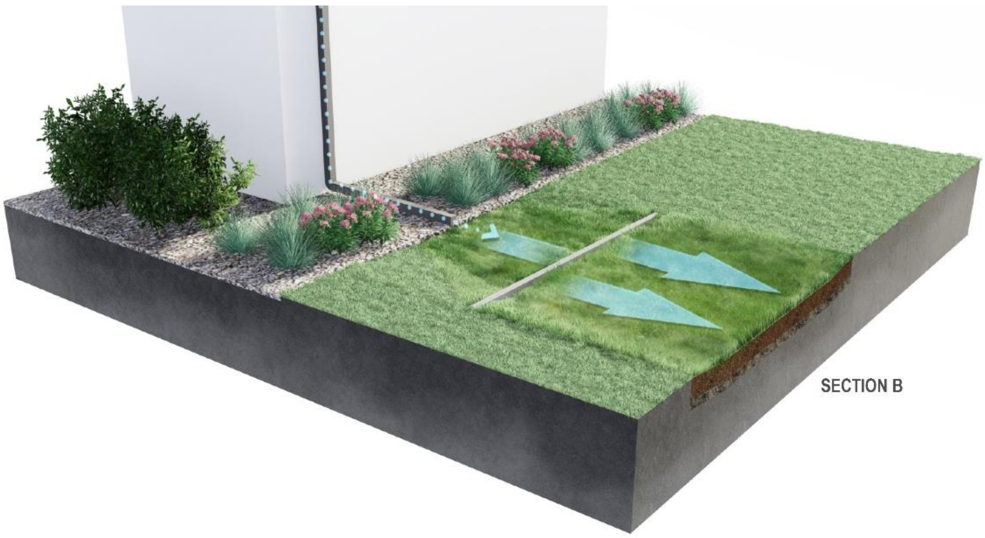


Figure 23. Application 1, Roof drain leading to level spreader and grass buffer

Figure 24. Application 2, Roof drain leading to a grass swale adjacent to a building

5.1.2 Roadways

Figure 25 and Figure 26 show PIAs that capture runoff from interior site roadways and similar pavement areas. Application 3 depicts a single opening in the curb that allows runoff from a larger section of pavement to drain into the PIA. A level spreader is indicated to distribute the concentrated flow from the curb opening. Application 4 shows a parallel grass swale along the far side of the roadway and a grass buffer on the near side. This application receives pavement runoff in a distributed manner; through periodic openings in the curb, as shown, or curbless edgers.

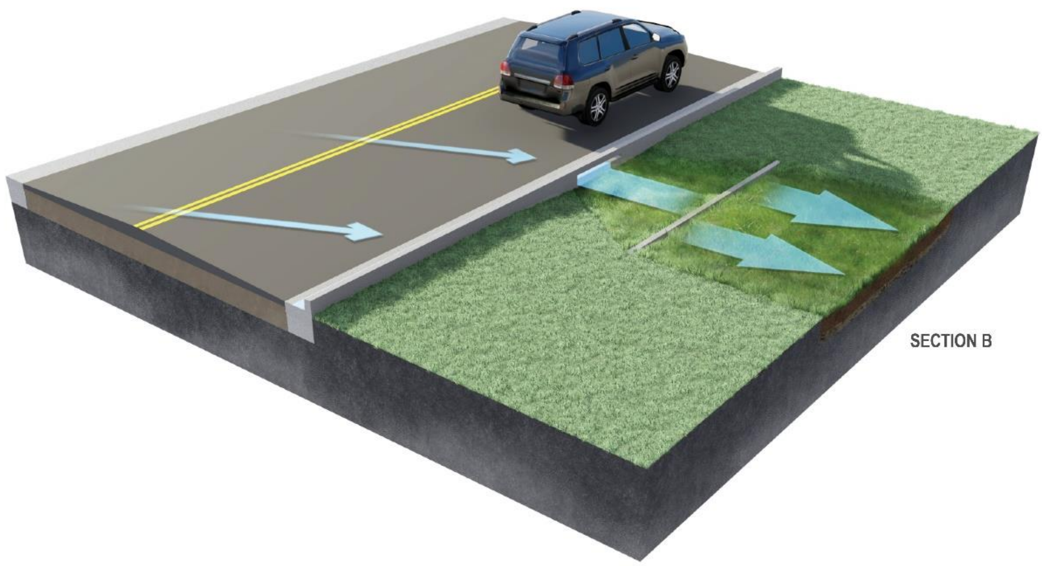


Figure 25. Application 3, Pavement draining through a single curb opening to PIA

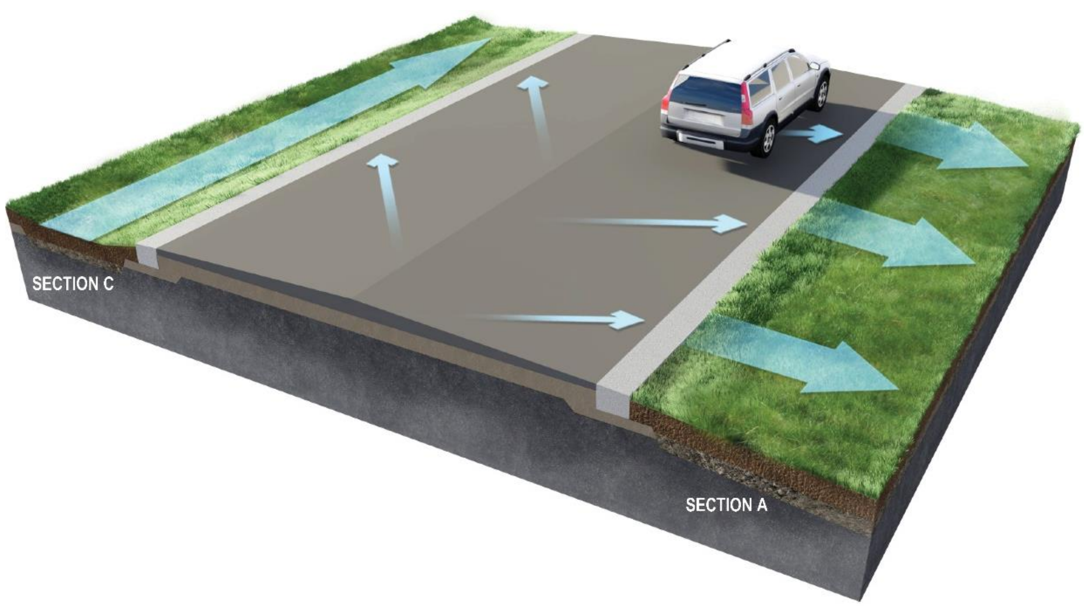


Figure 26. Application 4, Pavement flowing into grass buffer and swale

5.1.3 Parking Lot Islands

Figure 27 and Figure 28 illustrate applications of PIAs in parking lot islands within the interior of a site. Application 5 illustrates an island that receives flow from both sides, making the island the low point relative to the two adjacent parking bays. PIAs are more effective in linear islands that run parallel to a row of parking spaces, as compared to small individual parking islands. Application 6 receives flow from one side of the island, while the other side of the parking area drains away; this tends to be the case where there is dominant slope across a parking lot in one direction.

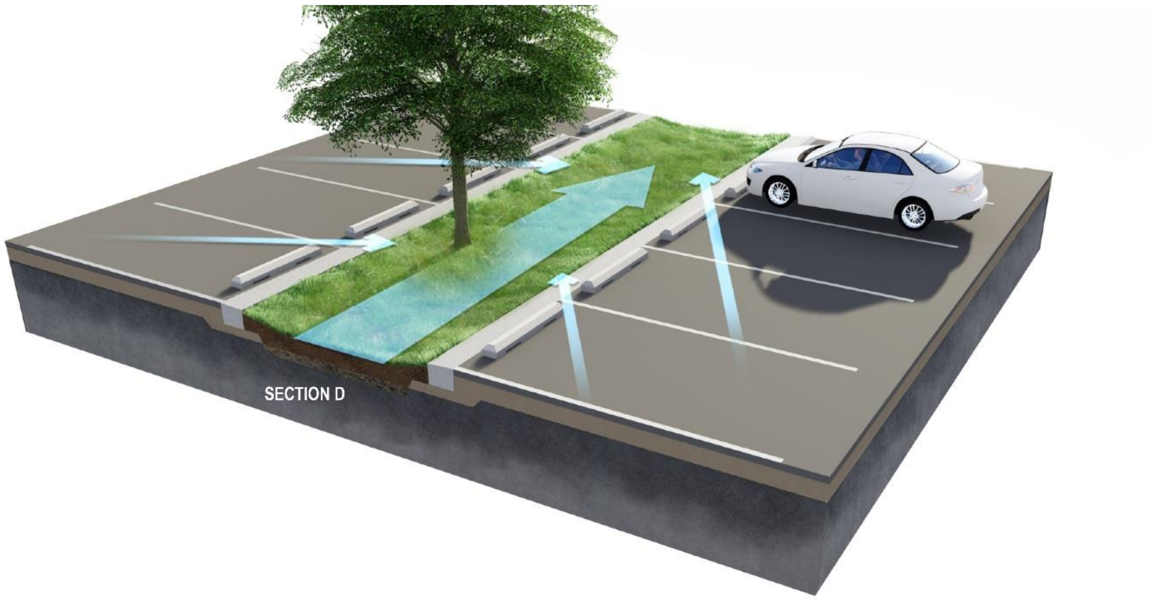


Figure 27. Application 5, Linear parking island receiving runoff from two sides

Figure 28. Application 6, Linear parking island receiving runoff from one side

5.1.4 Site Perimeter Setbacks

Figure 29 and Figure 30 show applications of PIAs within site perimeters that may also serve as screening buffers to diminish the views of parking lots. Application 7 depicts a setback buffer of at least 10 feet, while Application 8 illustrates a setback that has a width of approximately 20 to 25 feet. Screening vegetation (shrubs and trees) are shown on the side slope adjacent to the upstream pavement and a cobble ground cover is indicated in the shrub bed to provide erosion protection for runoff entering the landscape. Screening vegetation and landscaping details need to conform to the City's Landscape Code.

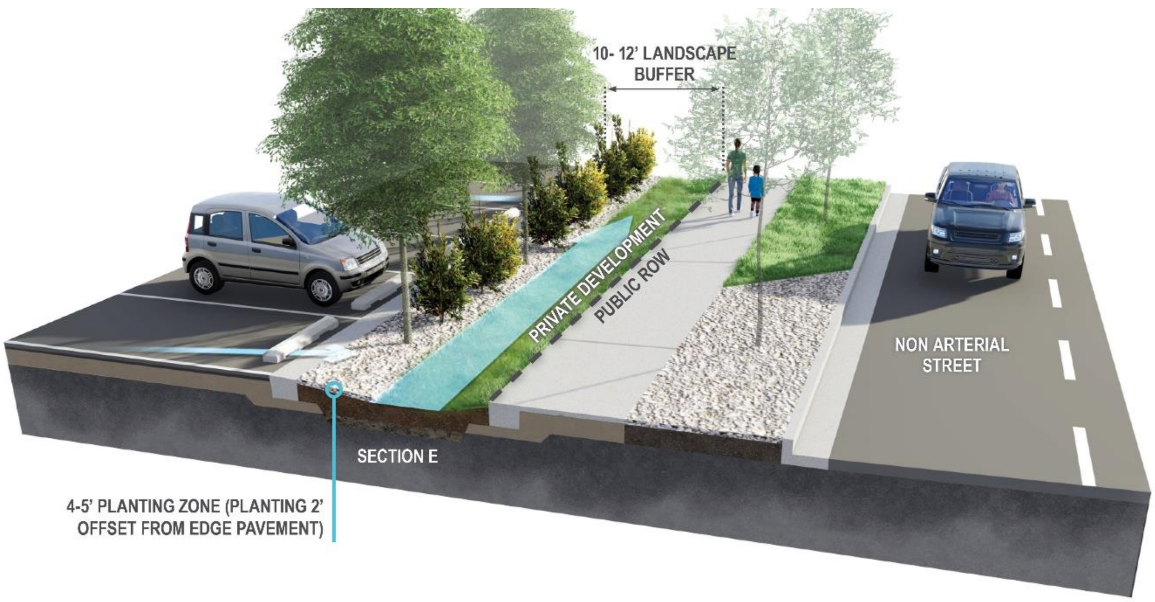


Figure 29. Application 7, 10'-12' perimeter landscape setback

Figure 30. Application 8, 20'-25' perimeter landscape setback

5.2 Cross Section Design

The design applications shown in the previous section feature several different cross sections and types of PIA applications. Grass buffers are often wider (perpendicular to flow) than they are long and typically include some type of pavement edge or level spreader to distribute and promote sheet flow. Grass swales are typically narrower and longer (parallel to the flow direction) than grass buffers, although a design goal for swales is to increase bottom width for greater infiltration area.

To provide effective rooting depth and infiltration capacity in buffers and swales regardless of the type of subgrade soils, 12 inches or more of favorable topsoil is recommended above nine to 12 inches of scarified subgrade. Topsoil should be specified based on the desired characteristics described in Section 4.1.

5.2.1 Grass Buffers

Figure 31 illustrates the cross section of a grass buffer (Cross Section A). Grass buffers are a type of PIA practice that receive runoff from pavement or a level spreader in a distributed manner, typically with low unit discharges. The width of buffers perpendicular to the direction of inflows may be 20 feet or more, as long as runoff is evenly distributed over the entire width. Preventing concentrated flow paths within grass buffers is extremely important for the long-term success of the practice. Components include a pavement edge or level spreader to distribute runoff followed by a turfgrass surface typically sloping from two to 10 percent that is graded level and smooth perpendicular to flow for an even distribution of stormwater runoff. Greater slopes, up to 25 percent, may be considered, although steeper slopes require more care in design, construction, and maintenance to avoid erosion and flow concentrations. A buffer is shown in Figure 26, Application 4, of the previous section.

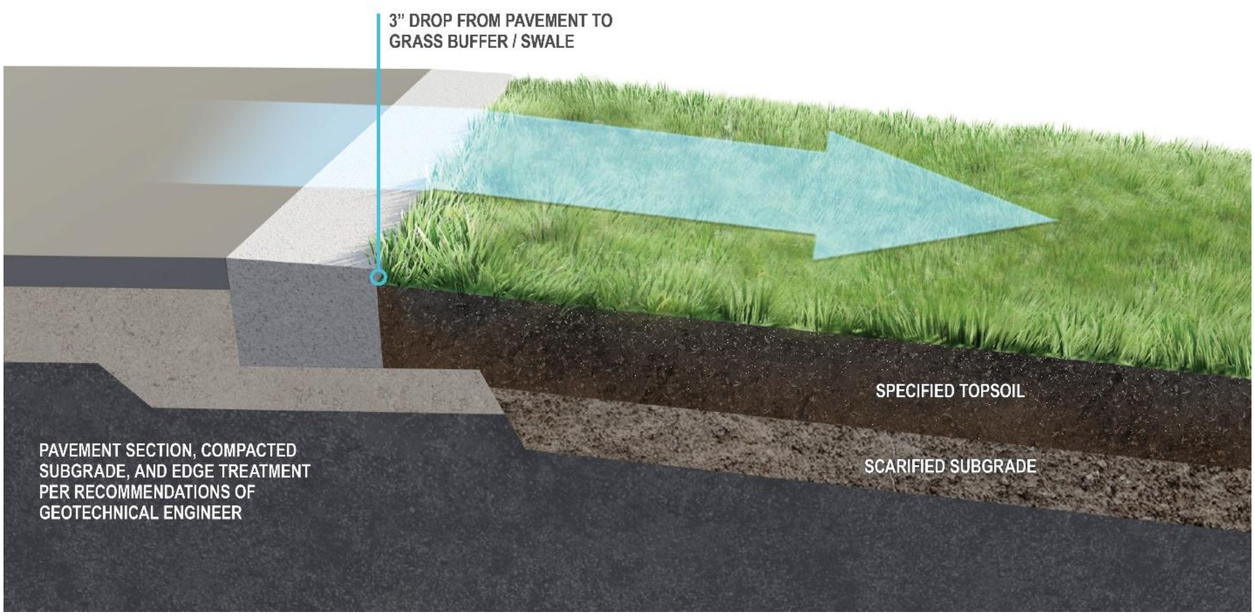


Figure 31. Cross Section A, Grass buffer receiving distributed flow

5.2.2 Grass Swales Receiving Upstream Inflows

Applications 1 through 3, in the previous section, utilize a vegetated swale with a bottom width that varies based on site conditions. Stormwater runoff enters at the upstream end of the PIA and is conveyed downstream. This type of cross section is depicted in Figure 32 (Cross Section B).

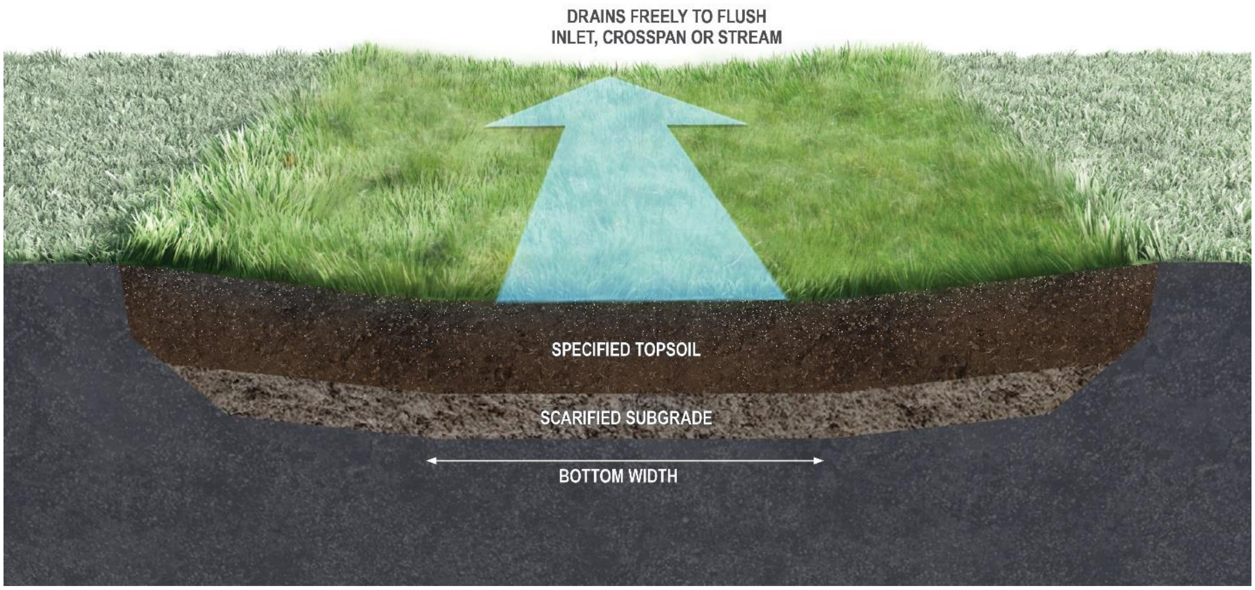


Figure 32. Cross Section B, Vegetated swale receiving flow from upstream

Flow depth may be as little as several inches during the water quality event; however, greater cross section depths are required to convey larger events, and freeboard should be considered. Bottom widths may vary from approximately five feet to as much as 20 feet if level spreaders are used to distribute the flow and sheet flow is achieved. Bottom widths may vary within individual swales and can be designed to have a more natural, curved shape. The bottom surface should be graded level and smooth perpendicular to flow to promote even distribution of shallow flows and avoid preferential flow paths.

Longitudinal slopes in the range of two to five percent generally perform well for grass swales. Wet conditions may develop if flatter slopes are used, since underdrains are not used in PIAs. Slopes approaching or steeper than five percent need to be checked for stability based on maximum design flow rates. Side slopes typically range from five to 25 percent.

5.2.3 Grass Swales Receiving Lateral Inflows

Applications 4 through 8 have pavement on one or both sides of the PIA practice; flow enters the length of the swale in a distributed manner along the sides. For the applications shown, runoff enters the side slope of the grass swale and turns once reaching the bottom to flow downstream in a linear direction. The side slope functions like a grass buffer, described above, so slope and grading recommendations are the same. Cross Section C, shown in Figure 33, features a concrete edge that is curbless with parking blocks, (curbless edges and flow-through curbs with frequent openings are other options as discussed in Section 4.3). Flow distribution through openings in flow-through curbs becomes somewhat more concentrated than curbless edgers, depending on the length and spacing of the openings.

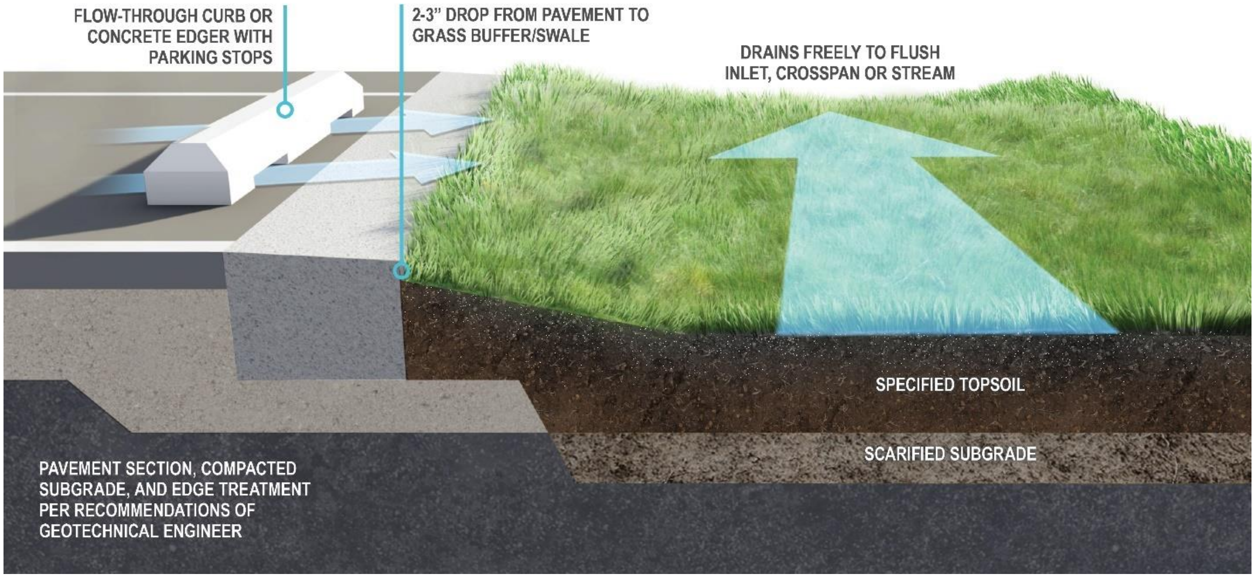


Figure 33. Cross Section C, Grass swale receiving lateral inflows from one side

Figure 34 (Cross Section D) illustrates a cross section that pertains to Application 5 with runoff entering from both sides of the PIA.

Figure 34. Cross Section D, Grass swale receiving lateral inflows from two sides

5.2.4 Multifunctional Landscape Planned Infiltration Areas

Figure 35 (Cross section E) illustrates a multifunctional landscape combining a tree and shrub bed that provides visual screening of a parking lot with an infiltration area, depicted in Applications 7 and 8 of the previous section. Care is required when laying out cobble to create a flat bottom width for sheet flow infiltration and avoid creating preferential flow paths, especially in narrower offset areas.

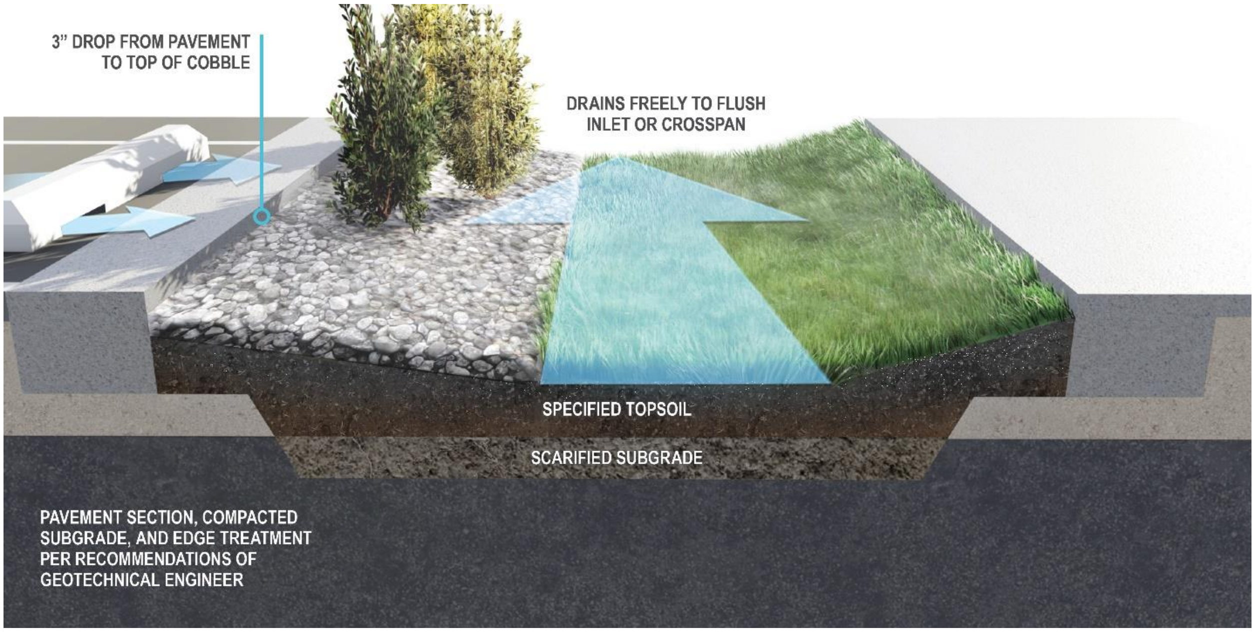


Figure 35. Cross section E, Multifunctional landscape PIA

5.3 Estimating Stormwater Volume Reduction

Volume 2 of the *Drainage Criteria Manual* describes methods to estimate the volume reduction within PIAs. The key parameters affecting the volume of runoff applied and the volume of runoff infiltrated are described below.

5.3.1 Ratio of Impervious Area Upstream of Planned Infiltration Area to Total Impervious Area

Designers are encouraged to drain as much of a site's roofs and pavement to PIAs as feasible (along with providing enough infiltration area to avoid overloading the PIAs). This will typically require multiple PIA features distributed close to and downstream of various impervious areas. The impervious area draining to any one PIA is recommended to be generally one acre or less.

5.3.2 Ratio of Planned Infiltration Area to Upstream Impervious Area

Ideally, PIAs areas are sized large enough to achieve water quality requirements for the upstream impervious area. Smaller PIAs are acceptable since it is beneficial to infiltrate a portion of the inflowing runoff in a water quality event; however, to avoid overloading PIA practices it is recommended that the ratio of infiltration area to upstream impervious area be 1:10 (10 percent) or more.

In general, smaller, distributed PIAs will be more effective than one large PIA. The wetted area of a PIA is the area that is in contact with runoff during a storm event equivalent to the water quality event, as defined in Volume 2 of the *Drainage Criteria Manual*. As mentioned, the ideal hydraulic condition for PIAs is to establish sheet flow at a depth below the top of dense grass shoots for maximum slowing, filtering, and infiltration of runoff. The infiltration area of a swale with inflows entering at the upstream end is equal to the average bottom width and wetted side slopes times its length. The infiltration area of PIAs with inflows from curbless pavement is generally estimated as the length parallel to the pavement edge times the width of the wetted landscape perpendicular to the pavement edge. If openings in a flow-through curb limit the continuous wetting of the slope, this needs to be accounted for in the estimation of wetted area. For calculations of wetted area to be accurate, it is critical that the top of the planting media be graded to very fine tolerances to avoid flow concentrations. Therefore, designers should provide clear plans and specifications and grades should be verified onsite during construction.

5.3.3 Representative Infiltration Rates for the Planned Infiltration Areas

The design guidance presented within this Manual calls for a sandy loam texture suited to infiltration and plant health, a sufficient depth of topsoil and subgrade scarification to encourage deep root growth and provide pore spaces for air and infiltrated water, and densely rooted vegetation to aid in sustaining infiltration processes. By following this guidance and ensuring careful construction and maintenance, it is acceptable to base infiltration rates on the specified texture of the topsoil (to be verified during construction), as long as limited disturbance and compaction occur after placement and a dense vegetation cover is quickly established. The methods for estimating stormwater volume reduction described in the *Drainage Criteria Manual* include information on selecting appropriate infiltration rates based on soil texture and vegetation cover. Reduced infiltration rates for mulch and cobble are also addressed.

5.3.4 Reducing PCM Size Based on Stormwater Volume Reduction

The required water quality capture volume of downstream PCMs (Step 2 of Four Step Process) may be reduced by the estimated stormwater infiltration provided by PIAs. If enough infiltration capacity is provided, in some cases a water quality based PCM may not be required for portions of a site.

5.4 Construction Considerations

One of the challenges of designers is to anticipate the information that is important for a contractor to understand and adhere to during the construction process. This is no less true for PIAs, and care is required in the preparation of construction drawings and specifications to communicate this important information. It is recommended that designers play a role during construction to observe the installation activities of PIAs.

Critical items during construction include:

- Avoiding disturbance of existing natural areas to be preserved.
- Stripping and replacing topsoil per the topsoil plan.
- Avoiding compaction and ensuring scarification of subgrade under PIAs.
- Obtaining topsoil that satisfies design specifications.
- Phasing installation of topsoil and vegetation after upstream site is stabilized and protecting PIAs from any sediment and debris remaining from construction activities.
- Precise fine grading of top of topsoil to promote sheet flow of stormwater runoff post-construction.
- Timely seeding, irrigation installation, and installation of blanket over topsoil immediately after topsoil installation.
- Ongoing observation and follow-up efforts to ensure establishment of dense vegetative cover and address any issues that reduce functionality.

Refer to the City's *Stormwater Construction Manual* (December 2020) and Colorado's Construction Stormwater Discharge Permit for additional guidance and requirements.

5.5 Maintenance Considerations

All stormwater management features (as well as all urban infrastructure) require maintenance. This is true for PIAs; therefore, clear maintenance plans and processes to ensure that maintenance is taking place are encouraged. Native vegetation, whether used in site landscaping or in Steps 1, 2, or 3 of the Four Step Process, has the potential to reduce long-term maintenance costs as a result of less mowing and lower fertilization and irrigation requirements. However, PIAs are not "no maintenance" and do require the following considerations:

- Establishment irrigation
- Periodic irrigation post-establishment
- Maintenance of irrigation equipment in a way that does not hinder sheet flow
- Inspection and follow-up care to ensure coverage and density of vegetation
- Weed management (application of herbicides needs careful consideration to avoid impacts to surface and groundwater)
- Avoidance of over-fertilizing to reduce likelihood of nutrient export
- Mowing operations
- Periodic aerating
- Removal of trash, excess soil and sediments, and biomass to maintain sheet flow conditions
- Avoidance of use of PIAs for snow storage

6.0 SITE EXAMPLES

A number of existing sites around the City were evaluated to see if existing landscape footprints could have been utilized for stormwater volume reduction via PIAs. Multiple land uses were examined including single-family residential, multi-family residential, warehouse, large commercial, small commercial, large retail, and small retail. These sites were not originally designed for volume reduction and there is no intent to retrofit them. These are "what if" scenarios to help illustrate how volume reduction could be integrated into site layouts that are representative of their respective land uses.

Aerial photography and topographic bases were obtained for each site and engineering site plans were reviewed for most of the developments. Based on flow patterns and the location of landscaping features, areas where PIAs could be implemented are shown in green and impervious areas upstream of the PIAs are shown in blue.

Minimal modifications to grading and crosspan and inlet locations were assumed for some sites; however, the majority of the existing layouts of the sites were retained. To keep the focus on PIAs, these site examples do not include integrating other infiltrative measures and PCMs such as bioretention, sand filters, and permeable pavement, even though these measures would be considered if these sites were originally designed with the intent of maximizing volume reduction. Additionally, if these sites were originally designed with volume reduction as the goal, it is likely that even more of the roof and pavement areas could be directed to PIAs than illustrated in these examples.

For each of these site examples, estimates were made of total site area, total impervious area, the sum of all "blue" impervious areas upstream of PIAs, the sum of all "green" PIAs, WQCV, and stormwater volume reduction in the PIAs as a percent of WQCV. Volume reduction estimates are consistent with methods described in the *Drainage Criteria Manual* and are based on infiltration rates that reflect adherence with the recommendations in this Manual. These values are summarized in tables accompanying each site example figure.

Conclusions from the example site investigation include:

1) Implementation of significant amounts of volume reduction did not require radical shifts in site layout from the existing site layouts. These "what if" scenarios would translate into reduced stormwater runoff volumes.
2) If these sites were planned and designed "from scratch" applying the volume reduction principles described in this Manual, it is likely that additional impervious area could be routed to PIAs, without loss of building square footage.
3) Volume reduction provides stormwater benefits on individual sites like these examples, but even greater benefits could be realized if implemented on a "macro-scale."
4) Each of the PIA applications (Applications 1 through 8) shown in Section 5 were employed in the site examples, highlighting that these are typical techniques that can be used while meeting landscaping requirements on a site.

6.1 Site 1 - Single Family Residential

Figure 36 illustrates how stormwater volume reduction using PIAs could be envisioned in this single-family residential neighborhood. Runoff is conveyed to a variety of grass swale PIAs capturing runoff from rear lots and in a central landscape area receiving street, driveway, and roof runoff.

Site 1 -- Single family residential	
Total site area, ac	17.36
Total impervious area, ac	7.75
Total site percent impervious	45%
Upstream impervious area (in blue), ac	1.67
PIA (in green), ac	0.83
WQCV, cf	12100
Stormwater volume reduction, cf	2160
Stormwater volume reduction as % of WQCV	18%

Figure 36. Site 1 – Single Family Residential

6.2. Site 2 – Single Family Residential

The PIAs shown receiving runoff from this lower density residential area adjacent to Site 1 illustrate a variety of applications. Figure 37 depicts back of lots draining to grass swales and streets conveying runoff to several configurations of swales.

Site 2 -- Single family residential	
Total site area, ac	7.00
Total impervious area, ac	2.60
Total site percent impervious	37%
Upstream impervious area (in blue), ac	2.06
PIA (in green), ac	0.53
WQCV, cf	4370
Stormwater volume reduction, cf	2150
Stormwater volume reduction as % of WQCV	49%

Figure 37. Site 2 – Single Family Residential

6.3 Site 3 – Multifamily Residential (Apartments)

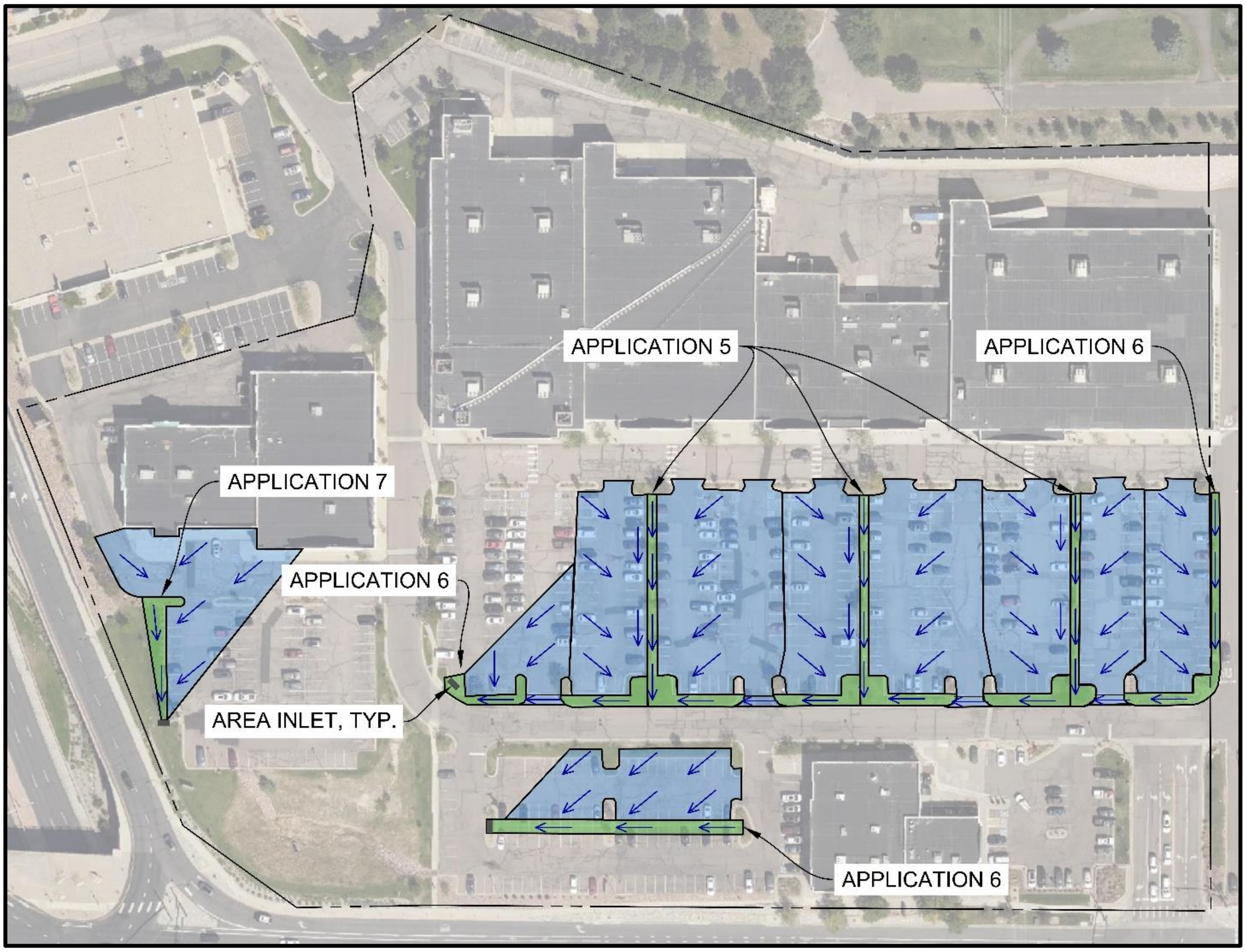
Portions of parking lots and roofs are directed to PIAs (linear swales and buffer areas) in this multifamily residential example site shown in Figure 38. Excess stormwater runoff that is not infiltrated within the PIAs is conveyed to area inlets at the downstream ends of these features.

Site 3 -- Multifamily residential (apartments)	
Total site area, ac	6.25
Total impervious area, ac	3.45
Total site percent impervious	55%
Upstream impervious area (in blue), ac	1.83
PIA (in green), ac	0.47
WQCV, cf	5010
Stormwater volume reduction, cf	2720
Stormwater volume reduction as % of WQCV	54%

Figure 38. Site 3 – Multifamily Residential (Apartments)

6.4 Site 4 – Large Commercial (Retail)

Figure 39 illustrates possible PIAs on this large retail example site, directing flow from parking areas to vegetated linear parking islands. Based on the grading of the site, several islands receive runoff from one side and several from both sides. Valley pans carry flow between islands to area inlets at the downstream end of the site.

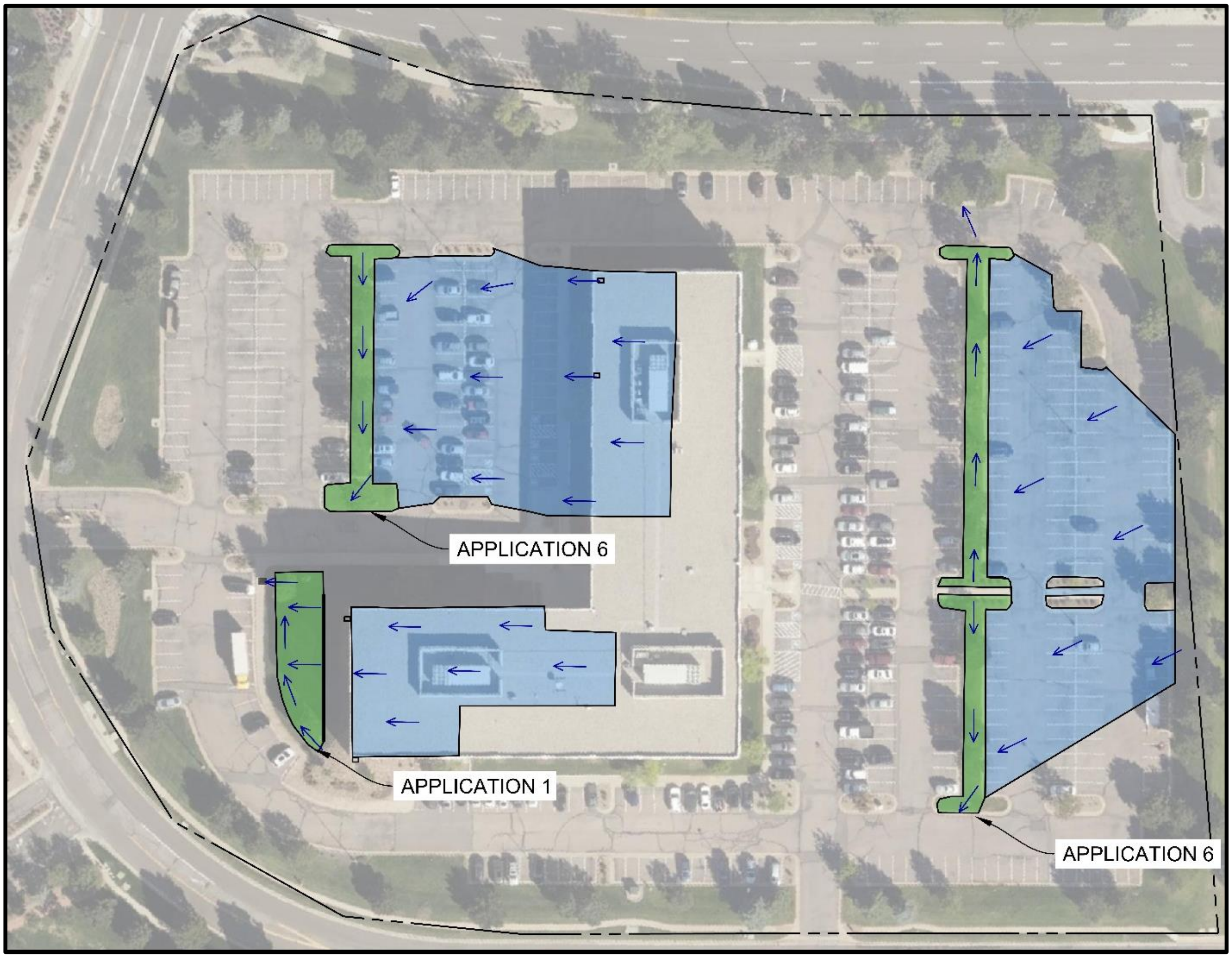


Site 4 -- Large commercial (retail)	
Total site area, ac	13.39
Total impervious area, ac	11.46
Total site percent impervious	86%
Upstream impervious area (in blue), ac	2.40
PIA (in green), ac	0.34
WQCV, cf	17800
Stormwater volume reduction, cf	2680
Stormwater volume reduction as % of WQCV	15%

Figure 39. Site 4 – Large Commercial (Retail)

6.5 Site 5 - Large Commercial (Office)

Figure 40 demonstrates PIAs that could be incorporated into this large office example site. Linear parking lot islands intercept flow from pavement and a portion of the roof. Runoff from another portion of the building is conveyed from roof drains to a level spreader that distributes flow evenly into a grass buffer.

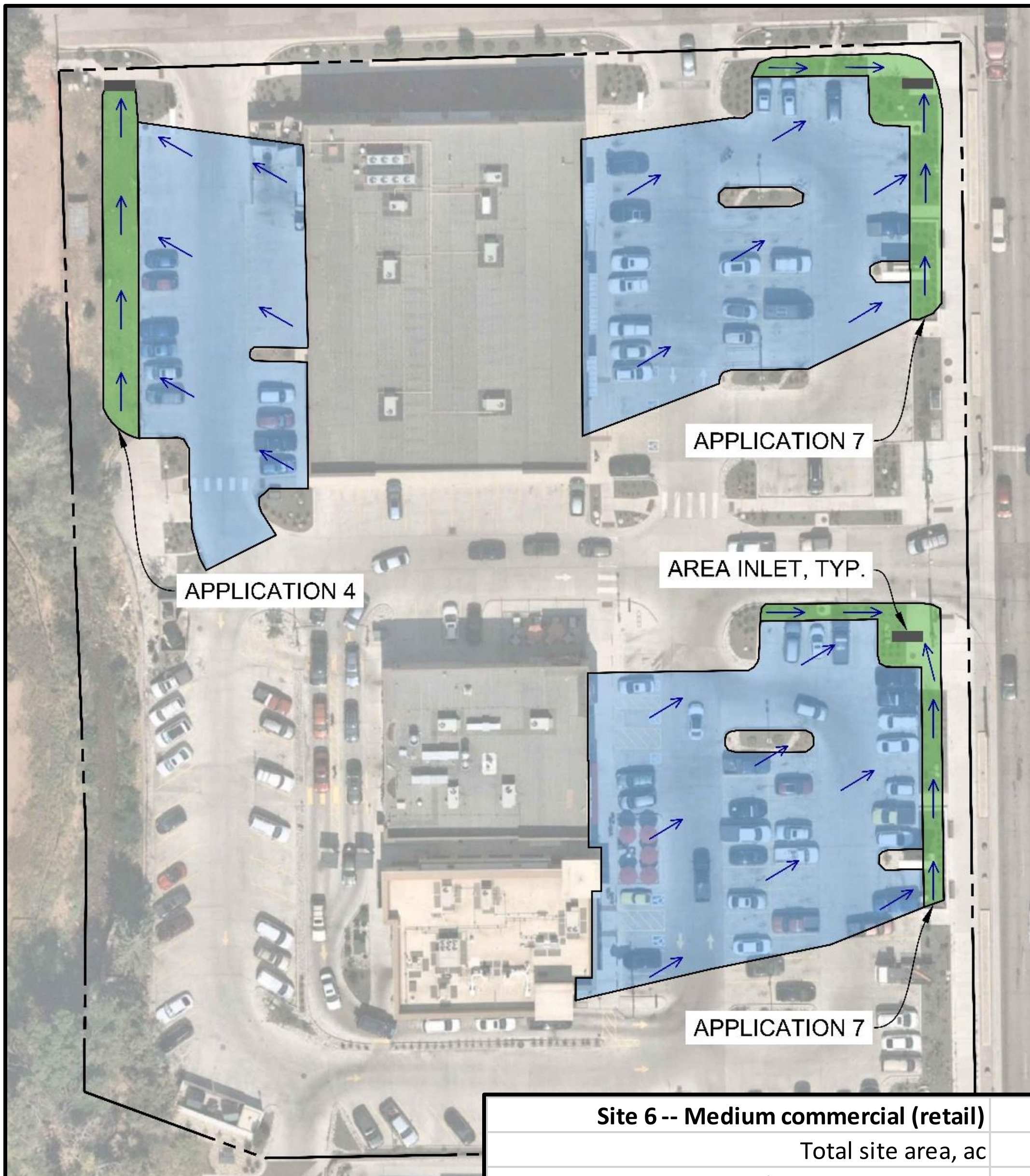


Site 5 -- Large commercial (office)	
Total site area, ac	8.10
Total impervious area, ac	5.39
Total site percent impervious	67%
Upstream impervious area (in blue), ac	1.58
PIA (in green), ac	0.27
WQCV, cf	7650
Stormwater volume reduction, cf	1960
Stormwater volume reduction as % of WQCV	26%

Figure 40. Site 5 – Large Commercial (Office)

6.6 Site 6 – Medium Commercial (Retail)

Parking lot runoff is shown in Figure 41 draining away from the retail buildings toward the site perimeter. Runoff flows into the PIAs for treatment and any excess runoff that is not infiltrated is carried to the area inlets at the downstream end of the practices.



Site 6 -- Medium commercial (retail)	
Total site area, ac	3.47
Total impervious area, ac	3.2
Total site percent impervious	92%
Upstream impervious area (in blue), ac	0.88
PIA (in green), ac	0.13
WQCV, cf	5270
Stormwater volume reduction, cf	920
Stormwater volume reduction as % of WQCV	17%

Figure 41. Site 6 – Medium Commercial (Retail)

6.7 Site 7 – Medium Commercial (Retail)

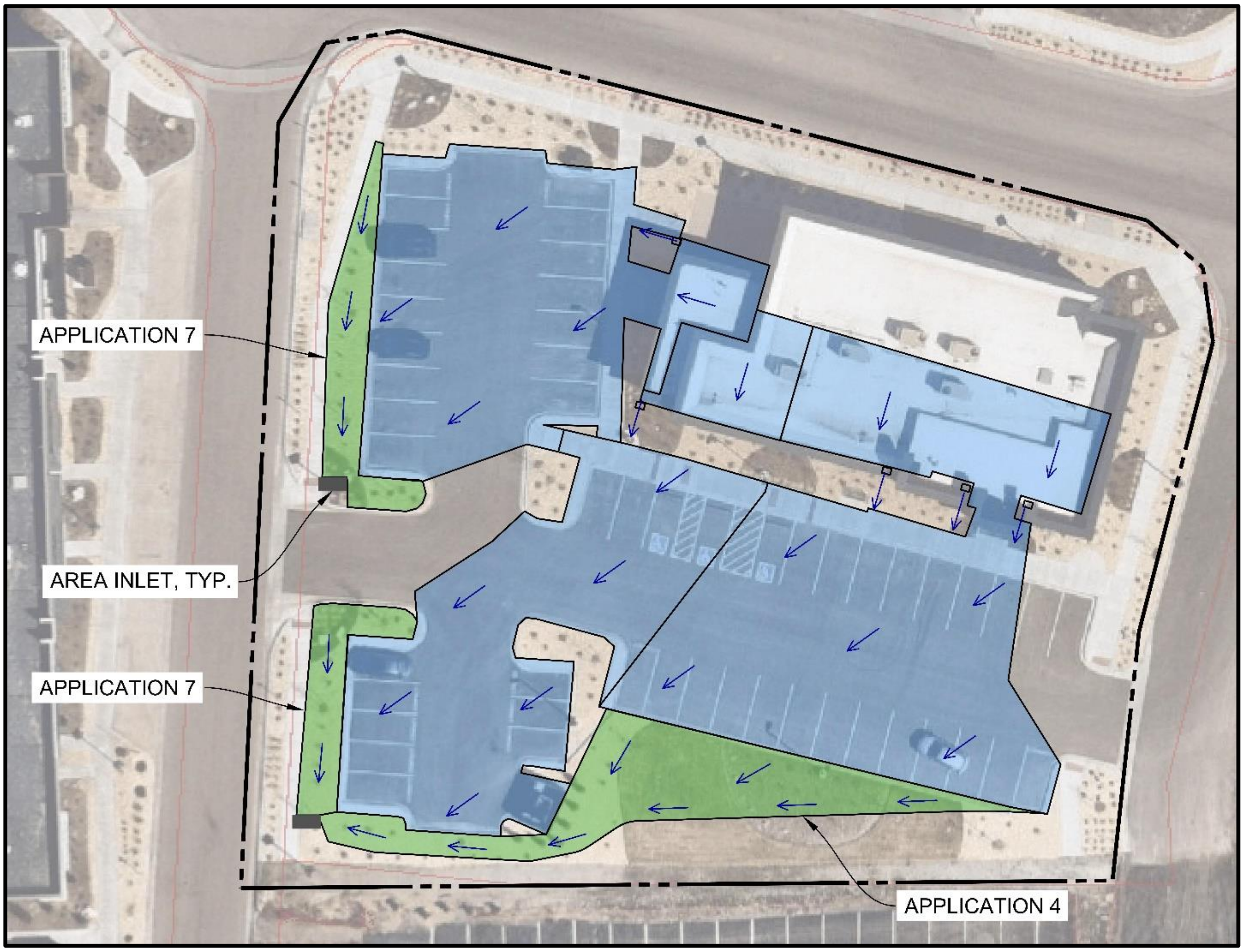
The existing drainage pattern on the medium size retail example site depicted in Figure 42 provides an opportunity to convey parking lot runoff to an adjacent grass buffer and swale. A curbless pavement edge or flow-through curb allows runoff to enter the PIA in a distributed manner. An area inlet at the downstream end of the swale captures any flows not infiltrated.

Site 7 -- Medium commercial (retail)	
Total site area, ac	1.89
Total impervious area, ac	1.63
Total site percent impervious	86%
Upstream impervious area (in blue), ac	0.33
PIA (in green), ac	0.10
WQCV, cf	2550
Stormwater volume reduction, cf	600
Stormwater volume reduction as % of WQCV	24%

Figure 42. Site 7 – Medium Commercial (Retail)

6.8 Site 8 – Small Commercial (Office)

This small commercial example site, shown in Figure 43 has several opportunities to incorporate PIAs. The pavement and sidewalks are graded and the flow from the roof is directed to drain to grass buffers and swales in landscape areas on the perimeter of the site. Perimeter landscapes could serve multiple purposes, providing visual screening and volume reduction.



Site 8 -- Small commercial (office)	
Total site area, ac	1.01
Total impervious area, ac	0.70
Total site percent impervious	69%
Upstream impervious area (in blue), ac	0.48
PIA (in green), ac	0.09
WQCV, cf	1000
Stormwater volume reduction, cf	620
Stormwater volume reduction as % of WQCV	62%

Figure 43. Site 8 – Small Commercial (Office)

6.9 Site 9 – Small Commercial (Restaurant)

The small restaurant building depicted in Figure 44 represents an infill project within a larger site. Parking areas drain to a PIA within the perimeter landscaping. This PIA could provide vegetative screening as well as infiltration.

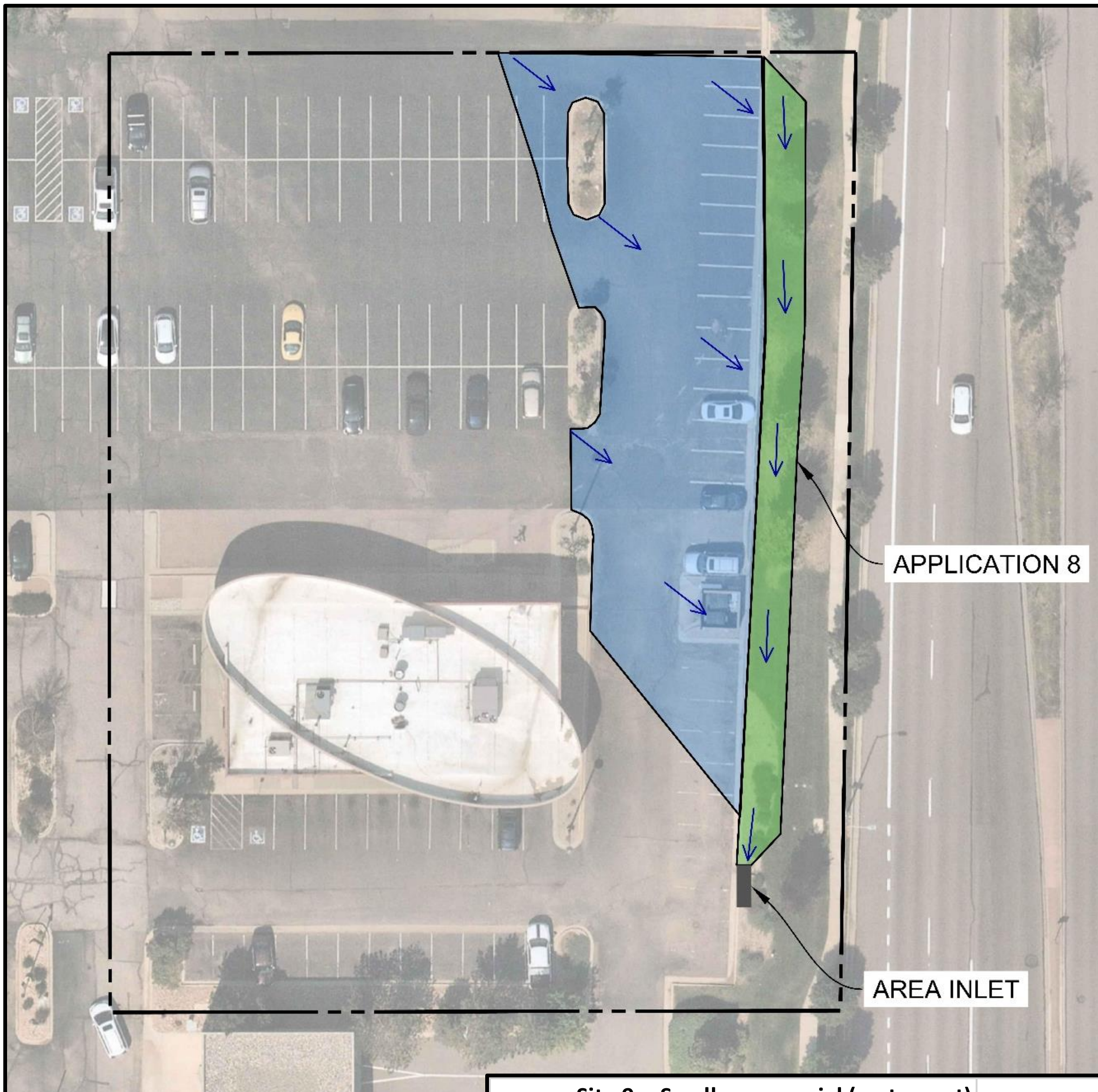
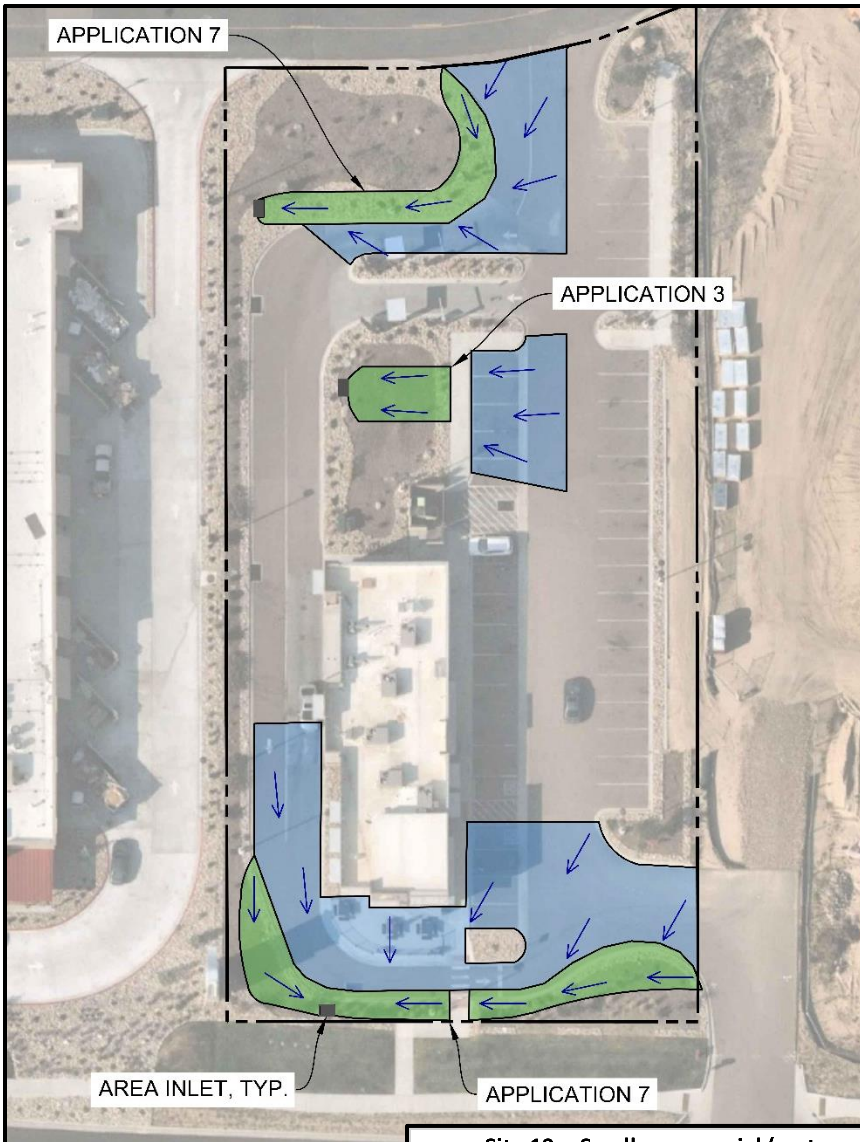


Figure 44. Site 9 – Small Commercial (Restaurant)

Site 9 -- Small commercial (restaurant)	
Total site area, ac	1.35
Total impervious area, ac	1.07
Total site percent impervious	79%
Upstream impervious area (in blue), ac	0.23
PIA (in green), ac	0.06
WQCV, cf	1590
Stormwater volume reduction, cf	420
Stormwater volume reduction as % of WQCV	26%

6.10 Site 10 – Small Commercial (Restaurant)

The grading and landscaping on this small restaurant site, shown in Figure 45 provides opportunities to incorporate PIAs in three locations. In each case, runoff from paved areas is directed to PIAs in adjacent landscapes as grass swales and a grass buffer with a level spreader.

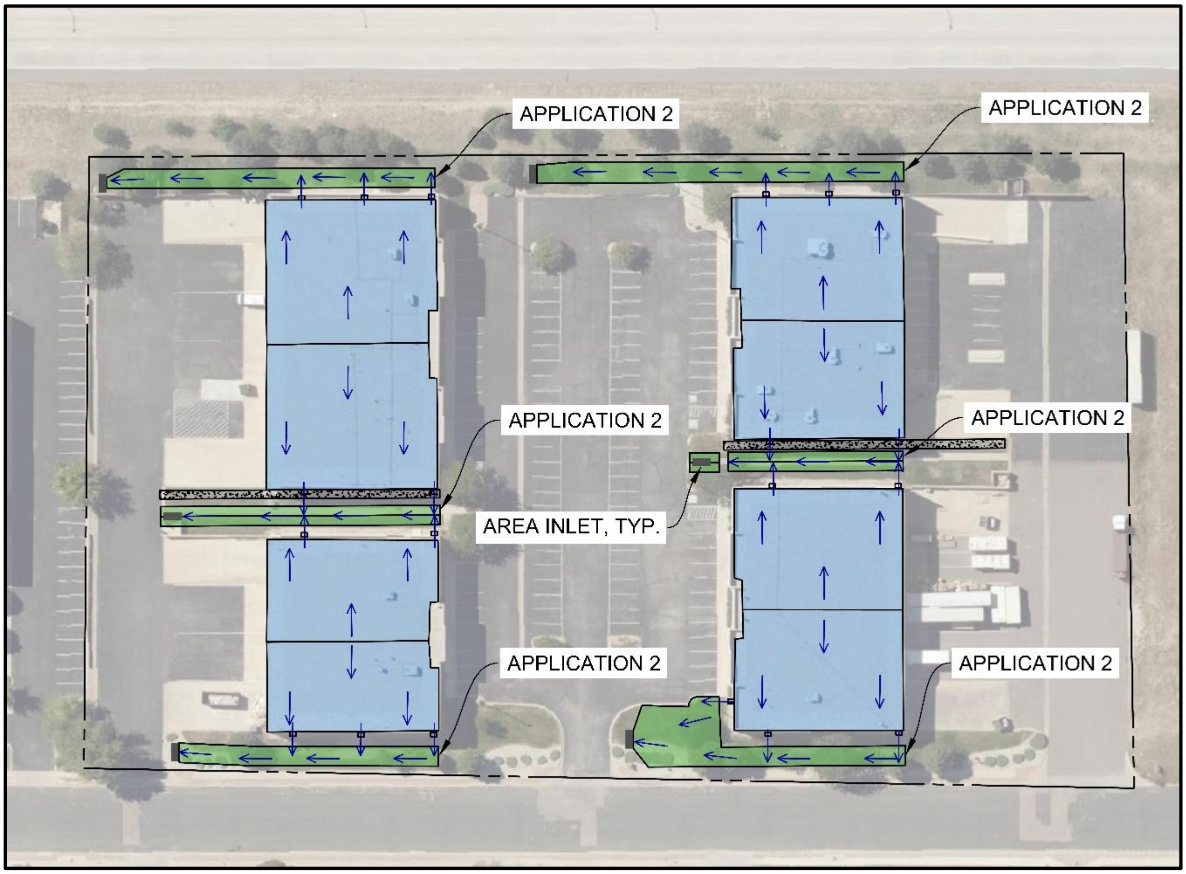


Site 10 -- Small commercial (restaurant)	
Total site area, ac	1.13
Total impervious area, ac	0.74
Total site percent impervious	65%
Upstream impervious area (in blue), ac	0.22
PIA (in green), ac	0.09
WQCV, cf	1050
Stormwater volume reduction, cf	410
Stormwater volume reduction as % of WQCV	39%

Figure 45. Site 10 – Small Commercial (Restaurant)

6.11 Site 11 – Warehouse/Industrial

Warehouses typically have less landscaping to impervious area ratios, but opportunities for implementing PIAs can still be achieved on the example site shown in Figure 46. Runoff from the building roofs is directed to swales in between the buildings and along the perimeter of the site. Runoff remaining at the downstream end of the PIAs is picked up in area inlets.



Site 11 -- Warehouse/Industrial	
Total site area, ac	5.67
Total impervious area, ac	4.59
Total site percent impervious	81%
Upstream impervious area (in blue), ac	1.42
PIA (in green), ac	0.32
WQCV, cf	6880
Stormwater volume reduction, cf	1870
Stormwater volume reduction as % of WQCV	27%

Figure 46. Site 11 – Warehouse/Industrial

7.0 DEFINITIONS

Four Step Process: The City requires the Four Step Process for receiving water protection that focuses on reducing runoff volumes, treating the WQCV, stabilizing drainageways, and implementing long-term source controls. The Four Step Process pertains to management of smaller, frequently occurring storm events, as opposed to larger storms for which drainage and flood control infrastructure are sized.

Grass Buffer: A strip of densely vegetated, sloped grass designed to accept sheet flow from upstream impervious areas and slow down stormwater runoff in order to promote filtering and infiltration.

Grass Swale: A trapezoidal, linear channel lined with densely vegetated grass designed to convey and slow down stormwater runoff in order to promote filtering and infiltration.

Green Infrastructure: In the City, the term green infrastructure refers to Step 1 stormwater infrastructure intended to mimic natural infiltration processes and includes the implementation of PIAs in site landscapes to achieve stormwater volume reduction. More broadly, green infrastructure refers to the range of measures that use plant or soil systems or other permeable surfaces or substrates to slow, filter, and infiltrate stormwater and reduce flows to sewer systems or to surface waters.

Level Spreader: A level spreader is used to disperse concentrated inflows in order to distribute flows evenly across the width of a grass buffer or grass swale. Level spreaders can be designed in a variety of ways (e.g., poured concrete weir), but should be designed to have a flat slope across the length of the level spreader to distribute flows evenly.

Minimize Directly Connected Impervious Area (MDCIA): MDCIA includes a variety of runoff reduction strategies based on reducing impervious areas and routing runoff from impervious surfaces over grassy areas to slow runoff and promote infiltration.

Permanent Control Measure (PCM): Control measures designed to permanently mitigate stormwater quality impacts due to development and redevelopment projects. Examples of PCMs include extended detention basins, bioretention, and sand filters.

Planned Infiltration Area (PIA): PIAs are vegetated, pervious areas that intercept stormwater runoff from nearby impervious surfaces (e.g., parking lots, roofs, roadways) to provide hydrologic and water quality benefits. Cobble ground cover and wood mulch may be used within PIAs with special design considerations.

Receiving Pervious Area (RPA): A synonymous term for PIAs, pervious area that receives runoff from upstream impervious areas and allows for infiltration.

Sheet Flow: The overland conveyance of stormwater runoff at a shallow depth as non-concentrated flow.

Stormwater: Stormwater runoff is generated from rain and snowmelt events that flow over land or impervious surfaces, such as paved streets, parking lots, and building rooftops, and does not soak into the ground.

Stormwater Volume Reduction: Reducing the volume of stormwater runoff is an application of Step 1 of the City's Four Step Process and involves directing runoff from impervious areas to planned infiltration areas in site landscapes. The reduction of stormwater runoff volume aims to reduce impacts on receiving waters by slowing runoff and promoting infiltration to move developed hydrologic regimes closer to the natural hydrologic regime.

Water Quality Capture Volume (WQCV): This volume represents runoff from the 80th percentile storm. Storms of this size occur more frequently than events associated with flood management and have been accepted as an appropriate event on which to base stormwater quality efforts.

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